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# Functional larval-parasitoid biodiversity in apple orchards as benchmark for management intensity and potential instrument for ecological amelioration of Iranian apple production.

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Affectionately dedicated to my wife, parents, brother and sisters

"And he who would not languish amongst men, must learn to drink out of all glasses; and he who would keep clean amongst men, must know how to wash himself even with dirty water"
(Beyond good and evil: prelude to a future philosophy by Friedrich Wilhelm Nietzsche)

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## List of abbreviations

| | |
|---|---|
| ADORAN | *Adoxophyes orana* Fischer von Röslerstamm |
| AGAPIN | *Agathis pini* Muesbeck |
| APAXAN | *Apantheles xanthostigma* Haliday |
| ARCCRA | *Archips crataegana* Hübner |
| ARCPOD | *Archips podana* Scopoli |
| ARCROS | *Archips rosana* L. |
| ARCXYL | *Archips xylostena* L. |
| ASCQUA | *Ascogaster quadridentata* Wesmael |
| BRAGEL | *Bracon gelechiae* Ashmead |
| CHOFUN | *Chorineus funebris* Gravenhorst |
| CYDPOM | *Cydia pomonella* L. |
| DEN | Denzlingen |
| EMM | Emmendingen |
| GOG | Goldener Grund |
| HEDNUB | *Hedya nubiferana* Haworth |
| HOH | Hohenheim |
| ILS | Ilsfeld |
| INT | integrated |
| INTS | intensive |
| IPM | Integrated Pest Management |
| LIOCAU | *Liotryphon caudatus* Ratzeburg |
| LOC | Lake of Constance |
| MACLIN | *Macrocentrus linearis* Nees |
| NEU | Neuhausen |
| ORG | organic |
| PANCER | *Pandemis cerasana* Hübner |
| PANHEP | *Pandemis heparana* Denis & Schiffermüller |
| PERTRI | *Perilampus tristis* Mayr |
| PHYPOL | *Phytodietus polyzonias* Foerster |
| PLI | Plieningen |
| PRIVUL | *Pristomerus vulnerator* Panzer |
| PTYLEC | *Ptycholoma lecheana* L. |
| RECLEU | *Recurvaria leucatella* Clerck |
| ROM | Romelshausen |
| SCAHIS | *Scambus hispae* Harris |
| SCH | Scharnhausen |
| SPIOCE | *Spilonota ocellana* Denis & Schiffermüller |

| | |
|---|---|
| TRIENE | *Trichomma enecator* Rossi |
| UNI1 | Unidentified 1 |
| UNI2 | Unidentified 2 |
| ST | Streuobst |

# 1. Introduction

Pest species attack seriously the plants used as human food source. The high intensity of crop management, on the purpose of plant protection, arises plentiful malicious arthropod species, microorganisms, and weed varieties. The unsustainable practices, such as application of chemical fertilizers and pesticides would exacerbate the pest problem by disturbing natural communities particularly on beneficial arthropods. The anthropogenic activities would change the energy or matter flow significantly affecting functional and guild complexes of natural enemies (Altieri 1994, Wardle et al. 1999).

The human interferences simplify the ecosystem by using toxicants, which disturb natural community interactions. Directly it reduces the number of adult beneficial through direct contact in a generation, and indirectly through vanishing shelter, food resource and alternative host, which leads to an ecological instability and the essence of self-regulation by natural enemies will be altered. These perturbations would be relieved by enhancement of functional biodiversity in agro-ecosystem. Thus, the ultimate purpose of conserving biodiversity in agriculture regardless to ethical concerns is to provide a variety of ecological services to control the undesirable organisms by predation and parasitization. Natural agents such as microorganisms, predators, and parasitoids inherently control the herbivore populations to some degree. These natural antagonists are able to regulate the herbivore density in agro-ecosystems. These regulations would be self-supported if the interactions between natural enemy and its host/ prey acts as dependent manner meaning the density of natural enemies increase when the density of their relevant host/ prey increases (Debach and Rosen, 1991 and Altieri, 1994). However, this natural regulation is not sufficient in terms of economic crop production when the economic injury level is lower than the injury level achieved under control by natural antagonists.

The sustainability in agro-ecosystem increases when biodiversity restores through the time and space, which enhances the chance to interact the coexisting species (i.e. beneficial and host species), and contributes to sustainability. A more complex food web contains more connections of species, which exhibit less oscillation of pest species and more parasitization rate. The stability of beneficial communities is promoted in a long-run management when the agro-ecosystem is enough diversified and human perturbations are minimized. The diversity in trophic interaction in a food web, solely does not lead to sustainability. Furthermore, the nature of density-dependence response would support the stability of natural arthropod communities (Southwood and Way, 1970). However, the species richness simply would not increase the ecosystem stability, the functional characteristics of each different species in a community may support the sustainability in ecosystems (Tilman et al. 1996 and Ewel, 1999).

*Biodiversity and its value to ecosystem functioning*

Biodiversity is the diversity of biological organisms, which can be scaled from gene and species to ecosystem and landscape. Striking anthropogenic impacts on ecosystem would affect the distribution and abundance of organisms in nature (Mooney 2002, Purvis and Hector 2000).

The biodiversity components used to assess and describe the invertebrate communities are number of species (species richness), number of individuals of each species (abundance), distribution of individuals (evenness), trophic/ guild structure, food web structures, and functional properties of species within a natural community, which are capable to affect ecosystem properties.

Species richness not merely considered as taxonomic species, each species may have diversified functional attributes and alters the energy fluxes, however several taxa may have similar functions. Even species with similar functions are not useless, because they are differentiated spatially and temporally by patches and isolated habitats (Vitousek, 1990, Hobbie 1992, Jones and Lawton 1995, Enquist et al. 2002, Hooper et al. 2002, Petchey et al. 2002, Tilman et al. 2002). The relative number of a species in an arthropod community cannot determine its importance; thereby rare species may play a pivotal role as keystone species in the ecosystem. Disproportionate to their rare biomass, they are capable to insert large effects on environment. It can be exemplified mostly by mammalians (i.e. tigers as predator), thus the knowledge on the role of keystone species in arthropod communities (parasitoids or predator) is poor or unidentified

The relationship between biodiversity indices and ecosystem functioning first was argued by MacArthur (1995) to tell differences between a simple vs. complex system stability and to recognize which components of biodiversity to which degree influences ecosystem functioning. However, May (1972) tried mathematically to indicate simple communities are more stable than complex ones. Furthermore, Pimm (1991) and Lawton and Brown (1993) indicate that stability enhances when the spices richness increases.

The beneficial community composition may affect the ecosystem functioning via species loss or changes occurred by anthropogenic interventions. One of the determinants of such changes in current study is manifested in parasitism rate, which functionally restrict number of pest species and effect on ecosystem properties (Chapin et al. 1997, 2000).

To make easy to perceive the concept of ecosystem functioning, it is considered into ecosystem properties, goods, and services. The properties relate to the pool of organic matter and rates of carbon transferring among different layers of trophic network. Ecosystem goods are food and substances, which fulfill human needs. Ecosystem services relates to the ecological infrastructures, which contribute to sustain the plant protection management through habitat complexity (i.e. connectivity of different habitats by corridors, alternative hosts, and wild flowering stripes to promote natural enemies' survival).

Many ecosystem properties are affected by natural biotic and abiotic factors oscillating year by year, so the amplitude of natural effects vs. human induced interventions cannot easily be determined to tell which factors to which degree influence the properties (Lubchenco et al. 1991, Chapin et al. 1996c, Valiela et al. 2000). Abiotic factors such as climate or human-induced interventions may affect the diversity of organisms, and thus, ecosystem functions (Grim 1995, Chapin et al. 1997, 2000; Loreau 2000b, Loreau et al. 2001, Lavorel and Garnier 2002).

*Functional diversity*

Earlier studies were conducted to find out if there is a relationship between biodiversity effects on ecosystem properties (Naeem et al. 1995, Tilman et al. 1996, Jonsson and Malqvist 2000, Engelhardt and Ritchie 2001). Species diversity as taxonomic concept would not necessarily link to such relationship. The collection of traits, which can be attributed to the functionality of a species based on its physiological and biological features, may shed light to involved complex mechanisms to realize the biodiversity effects (Odum 1969, McGrady-Steed et al. 1997, Naeem and Li 1997, Tilman et al. 1997a, Hector et al. 1998, Petchy et al. 1999, McGrady-Steed and Morion 2000).

To realize the changes occur in community composition, number of species and their relative abundance would not solely reveal the involved mechanisms accurately, unless to know the functional attributes of species. Functionality of a species regards to the impacts it may create in ecosystem and comprises of different aspects. The traits, which several species from the different taxa have, may similarly affect the ecosystem processes. These features, which set species into a group, are called functional groups or functional types. The biological traits vary per species. In a natural community by increasing the number of different species not only the taxonomic features but also the biological features diversify. The diversification of traits would contribute to higher functional attributes, which may affect the ecosystem functioning. For example, when natural antagonists' species of a targeted pest increase, they have a higher impact to control the pest population on different developmental stages of their hosts (e.g. egg, larvae, and pupae) (Gitay and Noble 1997, Tilman 2001). Consequently, different community composition enjoys different functional values, which can be expressed as relative abundance of functional attributes, diversity of species interactions in a community, and similarity on species functional traits (Martinez 1996, Tilman et al. 1997a, Walker et al. 1999).

The functional traits of parasitoid species in different scales within a natural community would influence the ecosystem and *vice versa*, which is so called functional effect group, and functional response group, respectively. The functional effect would be evaluated by mode of development of parasitoids with respect to the life history (endoparasitoid, ectoparasitoid), to sort of host affect (idiobiont, koinobiont), to host life stage (egg, larvae, pupa, adult, or combination of different stages), to morphological traits (ovipositor length, body size), to physiological features (egg production, rate of female production). The species richness and their composition vary in different habitats. In response to the changes in the environment, the functional traits would be filtered by climate change, anthropogenic perturbations, pollution, and habitat complexity, which affect the species survival by removing the sensitive species. The community composition exerts host extinction, or emigration, which consequently affect the higher trophic levels (antagonists) and eventually their functional attributes alter (Simberloff and Dayan 1991, Walker et la. 1999, Wilson 1999, Kendall and ward, 2016).

The functional effects also can be expressed by food web dynamics, which quantifies the number of species, and its complexities. The proportion of internal links among species (connectance) in a community would reveal the effect of habitat complexity on species interactions, which contributes to stabilize the ecosystem. However, the diversity-stability relationship in ecology is under debate and some studies indicate that higher diversity does not necessarily stabilize an ecosystem (Goodman 1975, Naeem et al. 1994,1995, Tilman et al. 2001, Dunne et al. 2005). It is still vague to tell if strong or weak links between coexisting organisms would contribute to stabilize the habitat (Naeem et al. 1994, McCann et al. 1998, Berlow 1999, Tilman et al. 2001).

*Parasitoid guild structure*

A functional effect group, which utilizes the same environmental resource in a similar way, is considered as guild (Simberloff and Dayan 1991). These sets of species would differ taxonomically but similar functions to some degrees. For instance, in arthropod communities, biological control agents (i.e. parasitoid species) may differ phylogenetically, but they parasitize the same host species (Fig. 1.1., data from Mills 2005). Each species may exploit one or combination of particular developmental stages in host/ prey, thereby these set of species constitute component guilds. Guild structure contributes to knowledge on synchronized and overlapped natural antagonists and pest populations. They will be useful in IPM to determine when is the best to take control measures, by considering the impact of mortality factor(s) on a specific host developmental stage, which leads to a satisfactory pest control and minimizing unnecessary pesticide applications.

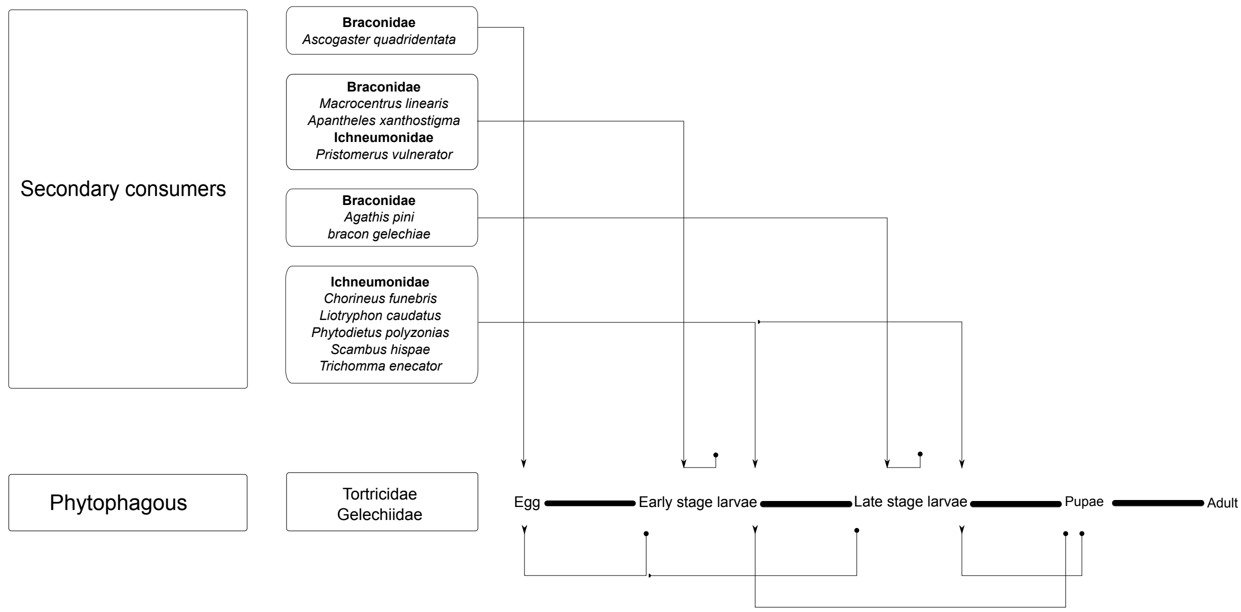


Fig. 1.1. Larval-parasitoid guild complex of Gelechiidae and Tortricidae (data from Mills 2005).

Theoretically, component guild comprises of one natural enemy, which restricts niche overlapping by constituent members of the guilds and decrease the intra-guild competition even when the generalists are numerous in the guild structure (Miller and Ehler 1990, Ehler 1992, Godfray 1994, Mills 1994a).

The antagonistic guild would be altered by changes in habitat complexities, host abundance, and competition (Ehler and Hall 1982, Ehler 1992, Mills 1992, 1994). When the natural antagonists show a density dependence manner on their host density, broad-spectrum pesticide application would be extremely destructive on beneficial communities, which arises pest resurgence. Furthermore, higher species richness constituting guild component would contribute to complementarity effectiveness of beneficial rather than number of individuals in a long-term approach (Miller and Ehler 1990).

*Beneficial biodiversity and management of agriculture*

The value of biodiversity in context of beneficial arthropods would result into their crucial efficiency to control pest population as natural agents, which furthermore by conservation would contribute to sustainability of ecosystem. The importance of beneficial is hard to realize, because their presence or activity ascribe to limiting environmental factors or human induced perturbations and knowledge on their biology is poor (Johnson and Wilson 1995, Hughes et al. 2000, Mikkola, K. 1989). These undervalued organisms are natural agents, which can be used in agriculture to promote the guarantee of healthy and sustainable crop production. However, their importance as functional component and top-down control agents on host density has been neglected. In order to keep the pest damage under the economical thresholds, beneficial arthropod may serve ecologically to increase the ecosystem functioning through energy fluxes and trophic levels (Wilson and Huffaker, 1976, Straub et al. 2008).

However, the efforts done to monitor the pest's activity have been focused mostly on short-term approach via increased number of individuals of one or a few beneficial species (i.e. inundating methods), the long-term approach (particularly for wasp's species, which are difficult to reproduce while in captivity) emphasizes to maintain the species richness by conserving strategies. This approach enjoys a higher resistance against perturbations and disturbances with a long-term complementarity control, because a community containing higher species richness consequently has diversified functional traits, which eventually increase the stability of ecosystem. (Tilman 1996, Bengtsson et al. 2003, Duelli and Obrist 2003). Furthermore, compared to chemicals and entomopathogenic bacteria or viruses, hosts rarely develop resistance against parasitoid species. Current studies also indicate the importance of natural enemies' diversity on pest density regulation (Loreau and Hector 2001, Finke and Denno 2005, Rosenheim 2007, Schmitz 2009, Snyder et al. 2006, Straub et al. 2006, Straub et al 2008, Wilby et al. 2005, Yachi and Loreau 1999). Contradictory a beneficial arthropod through competitive interactions with other natural enemies (i.e. intra-guild competition) may lose its effectiveness (Ehler, 1994, Finke and Denno 2002, Meyhöfer and Hindayana 2000).

The beneficial arthropods, mostly from Hymenoptera, encompass a wide range of parasitic wasps in Ichneumonoidae comprising of two important families (Ichneumonidae and Braconidae). These two families are highly diverse compared to the rest of families in arthropods. The biology of most species is unknown. Their part of development would be done inside or outside of their host. They are also functionally diverse and can exert mortality impact on their hosts. They kill their host gradually (koinobiont) or instantly (idiobiont). Koinobionts are usually endoparasitic (feed inside host body) and idiobionts are ectoparasitic (feed outside the host body) (A1.1.) (Kendall and Ward 2016). Endoparasitoids need to overcome immunological constraints, whereas idiobionts are less restricted so they enjoy higher host ranges (Askew and Shaw 1986, Santos et al. 2011). Thereby disturbances may change part of matrix of functionalities specifically on idiobionts, which seemingly utilize a higher range of resources (Kendall and Ward 2016).

*Biodiversity crises and anthropogenic perturbations*

To increase crop production, the scales of local and global environment have been influenced by human interventions. The widespread agro-ecosystems and commercial developments have led the biodiversity and its components (natural communities and their composition) to be altered. The consequences of such changes have brought serious concerns on functionality and ecosystem properties (LaSalle and Gauld, 1992, Kunin and Lawton 1996, Schwartz et al. 2000, Hector et al. 2001b, Minns et al. 2001, Sax and Gaines 2003).

There are still controversies if community and its features may interact with the functioning of ecosystem, or if known factors are accurate enough to divulge natural complex mechanisms. The amplitude of human perturbations on biodiversity changes and natural oscillations, which occur year by year, may exert changes to some degrees and make the story more complicated to tell which factors are responsible to which extend? The human unsustainable practices such as chemical application may affect the pest and natural enemies' populations. To depict such destabilizing effects, resurgence and pest outbreak can be exemplified. The consequences of toxicant application may result to remove the sensitive natural enemies and yield to explosion of pest population. However biotic factors such as host, pathogen, predator, and parasitoid interactions may exert changes to shift an herbivore to a dynamic and cyclic state (Dwyer et al., 2004, Hesketh et al., 2009). Additional to the indirect effects of human-induced practices, which restrict the natural resources for beneficial, it effects directly on the survivorship of natural enemies (Atlas, 1984, Hobbs abd Huenneke, 1992).

The direct and indirect detrimental effects of pesticides on third trophic level (predators and parasitoids) have been demonstrated by different studies (Langhof et al. 2003, Gonzales-Zamora et al. 2004, Koss et al. 2005, Langhof et al. 2003). The negative effects of toxicant application would extend to beneficial behavior, reproduction potency, foraging, sub-lethal effects, rate of parasitism, and biodiversity (Basedow 2002, Salerno et al. 2002, Desneux et al. 2006).

The negative impact of broad activity of pesticides has demonstrated on natural enemies. Furthermore, honeybees, which have a profound impact on agricultural production, suffer from the non-target effect, which result to economical loss (Desneux et al., 2007).

The adverse effects of pesticides do not constraint to the arthropod species and communities and they would affect other components of the environment. According to the report by Millennium Ecosystem Assessment (2005) pesticides are capable to exert ecosystem harm and social consequences. Microbial communities and soil born creatures are not exempt of such inconveniencies. In addition to terrestrial species, the aquatic organisms would be affected as non-target animals.

Biorational synthetical pesticides and bio-based pesticides, with active ingredients detrimental to herbivores but exerting less disruptive effects on beneficial arthropods shall replace broad-spectrum pesticides in future. Often such pesticides are derived from natural agents such as microorganisms or plant extracts, which the active ingredient is specific to target pests and minimize the exposure of antagonists.

The amplitude and effect size of pesticides to kill the natural enemies and their persistence in the environment (sub-lethal effects) varies on their active ingredients. When pesticides remove natural enemies, the herbivore population would recover due to the absence of their relevant antagonists. Thereby pest resurgence may occur. Thus, a total recovery of the antagonist populations may take more than a vegetation period, depending on e.g. field size, antagonist biodiversity, and number of pesticide applications. However, broad-spectrum pesticides kill the other parasitoids, which control the unimportant pest. This situation shifts a pest to the primary and key pest in the absent of antagonists (Kogan and Hilton 2009).

By the time, genes responsible to detoxify the poisonous substances would be developed against a pesticide. These genes are transferable to the next generation; thereby the pesticides become useless and lose their effect. However, if the formulation of pesticides function with the same mode of action, the probability of resistance in pests would increase. Worldwide, at least 586 species of arthropod pests developed resistance to one or more insecticides with, in total, more than 10,000 cases of resistance (Sparks and Nauen, 2015).

The toxicants used against pest arthropods would affect mammals as well. The exposure of the farmers to pesticides directly while handling and application often leads to hospitalization and casualties. Annually, millions of pesticide poisonings is reported from developing countries (Paoletti and Pimentel 2000, PAN Germany 2012).

*Plant protection management and its effects on biodiversity*

Maintaining an intact ecosystem with an almost undisturbed, effective functional biodiversity to control arthropod pests may be possible at best in perennial crops, such as fruit orchards, compared to annual crops which underlay a certain species fluctuation depending on crop rotation regimes. Restoring or recovering an effective functional diversity depends on *status quo* of crop protection intensity. Biodiversity is negatively correlated with crop protection intensity. Therefore, a survey was conducted to assess the agronomical, technical and educational background of apple farms in Iran to monitor an apple production unbiased by mostly advanced IPM or organic production in Central Europe, which is expected to consider biodiversity aspects.

*The expected outcome of the current research*

In fact, the prevalent of conventional apple orchards in Iran makes it difficult to find semi-abandoned orchards and to tell the differences between these two types of managements. Thereby the sampling occurred in Germany. The survey on 39 apple growers can be used as background information to improve or to optimize the apple production ecologically, which leads to a more balanced concept to implement IPM in Iran. However, this study does not depict a holistic approach to analyze different aspects involved in IPM achievement and management, it provides a fraction of intricate network to reply some current obstacles to launch a friendly management (ecologically based methods) to ecosystem.

## 2. Material and methods

### 2.1. Field surveys

#### 2.1.1. Sampling methods

To collect leafrollers and codling moth, random observation and mass sampling of pupating / hibernating larvae by fixing corrugated cardboard around the apple tree stems were conducted.

We visually searched for leafrollers larval shelters where they feed on the leaves in interior and exterior of apple canopy, examining both the upper and lower half of the tree. The infested leaves were transferred to laboratory and were placed individually into the small plastic cups covered with a lid (Licefa, Art. Nr. V 1-21, specified 42 x 51 x 6 mm width x length x height). If necessary, the young larvae were fed with fresh young apple leaves enabling them to complete preimaginal development or to let the prospective adult parasitoids emerge.

Corrugated cardboards (16 cm broad, Papier Brinkmann GmbH, Art. Nr. 350600100) were fixed in summer and autumn with expected beginning migration to pupation / hibernation sites, and removed and taken into the laboratory, when larvae should have all found there for pupation or hibernation sites. The cardboards were installed in the lower part of the trunk near to the ground, which is convenient for the larvae to hide. To protect the cards against birds´ attacks, mostly crows feeding on aestivated larvae, the cardboards were taped (Tesa Paketband), which resisted well bird picking. In some few cases, bigger birds could destroy the cardboards totally when larvae were abundant. After removal of cardboards and transfer into the lab, the hiding larvae were taken and kept in groups of 10 to > 30 larvae in plastic boxes under room temperature until pupation / adult emergence or parasitoid emergence.

The reared adult parasitoids were collected and preserved in alcohol 70% for further taxonomic identifications.

#### 2.1.2. Host and hymenopteran parasitoid identification and taxonomic affiliation

Identification of hosts was done in the larval stage following (van der Geest and Evenhuis, 1991) and of adults emerged from the larvae collected. Parasitoid species were determined by morphological features under a binocular (Zeiss Stemi IV). Subfamilies of Braconidae and Ichneumonidae were distinguished following Wharton et al. (1997) and Broad (2011). The subsequent species identification followed Mills and Carl (1991). For identification of Chalcidoidae the key of Gibson et al. (1997) served well. If species were not identifiable the specimens were considered with their field number only.

## 2.2. Calculation of ecological indices

*Dominancy and classification*

A logarithmic division for classification of species dominance, which describes the relation between species and individuals of a community, was introduced by Tischler (1949) (Table 2.1).

Table 2.1. Dominance scale by Tischler (1949).

| **Dominance scale** | **Ratio of specimens per species (%)** |
|---|---|
| Subrecedent | 0 % < $D_i$ < 1 % |
| Recedent | 1 % ≤ $D_i$ < 2 % |
| Eudominant | 10 % ≤ $D_i$ ≤ 100 % |
| Subdominant | 2 % ≤ $D_i$ < 5 % |
| Dominant | 5 % ≤ $D_i$ < 10 % |

*Fauna similarity*

In addition to the diversity, also the faun similarities can be described with indices of species composition. Jaccard index, also known as the Jaccard similarity coefficient used for comparing the similarity and diversity of sample sites (Mühlenberg, 1989).

Jaccard´s index is calculated as:

$$JZ = \frac{G * 100}{S_A + S_B - G}$$

Where: *G* = number of species in both areas together, and SA*,* *SB* = the number of species in area A and area B

Renkonen index is a measure of similarity for each community sample as percentage (Krebs 1951). This index ranges from 0 (no similarity) to 100 (complete similarity).

$$P = \sum_i minimum\ (p_{1i}, p_{2i})$$

Where: *P* = percentage similarity between sample 1 and 2, *P1i* = percentage of species i in community sample 1, and *P2i* = percentage of species i in community sample 2

*Wainstein index*

This takes into account of the common species and their frequencies (Mühlenberg, 1989). It is simply the product of multiplication of both Jaccard and Renkonen index.

$$K_w = P * JZ$$

*P* = Renkonen´s number

*JZ* = Jaccard´s number

*Fauna change*

Fragmentation of habitats may be the products of human interventions, which affect species composition (here represented by larval-parasitoids). The scarcity of food in highly fragmented areas forces the species to leave the patch to find resources. The rates, which a species appears or disappears in a patch, are proportionate to the degree of fragmentation and anthropogenic disturbances. Community composition changes can be expressed in turnover rates through the time (Mühlenberg, 1989). The species turnover is calculated as follows:

$$T = \frac{J + E}{S_I + S_{II}}$$

*J* = number of species which have been added between season I and II

*E* = number of species which have disappeared between I and II

*SI* = number of species in season I

*SII* = number of species in season II

*Shannon index*

The Shannon index considers the species richness and their relative abundances. A higher diversity index represents a higher evenness in a community, which shows all species in the community are equally abundant and have the same chance to utilize natural resources (Mühlenberg 1989).

$$H_S = \sum_{i=1}^{S} p_i ln\, p_i$$

$$p_i = \frac{N_i}{N}$$

*HS* = Shannon diversity

*S* = total number of species

*Pi* = probability of the occurance of type i, *i.e.* the relative frequency of the i-th species of the total number of individuals

*N* = total number of individuals

*ni* = number of individual of species i

HS value rises with the number of species and increasing equal distribution of individuals on the species. The lowest value 0 results for just one kind of existing. A maximum diversity is achieved with equal frequency of all types.

*Simpson index*

The Simpson index indicates the likelihood whether two randomly selected individuals in an indefinitely large species community belong to the same species (Magurran 1988)

$$D = \sum p_i^2$$

*D* = Simpson diversity

*pi* = probability of the occurrence of type i, i.e. the relative abundance of the ith type from the total number of individuals.

*Food web illustrations*

To illustrate the bars representing host and parasitoid communities, the percentage of each species (which attacked and being attacked) per year for each single of different locations in Baden-Württemberg was calculated as follows:

$$Percentage\ of\ species\ = \frac{n_i * 100}{N}$$

Where: *ni* = relative abundance of species i within the community (host or parasitoid), *N* = total abundance of species within the community (host or parasitoid)

To illustrate host and parasitoid association, the percentage of parasitism was calculated as follows:

$$Percentage\ of\ parasitism\ = \frac{n_i * 100}{N}$$

*ni* = relative abundance of parasitoid species i

*N* = total number of host species

*Food web connectance*

Interaction diversity is directly analogous to species diversity. In its simplest from (i.e. interaction richness), it is the number of interactions or links within the network. However, just as species diversity can be more than just species richness, interaction diversity is usually measured in terms relative to the number of species in the network (e.g. connectance), rather than interaction richness (Tylianakis 2009).

A higher connectance represents a higher species interaction in natural food web. Higher natural antagonist diversity may lead to a greater pest control. A diversified natural beneficial community would have a complementarity effect on the herbivore populations, and it would stabilize the rate of parasitism and/ or consumption through the time even if the environmental condition varies (Loreau 1988, Snyder et al. 2006, Tilman 1977a, b). Environmental changes would affect some of the natural antagonist species, but some other species existing in the guild may compensate to control the pest population by the time. On the other hand, a higher diversified community does not react the same to the environmental changes and some species would have fitness to tackle the inconveniences (Elmqvist et al. 2003).

Furthermore, a higher number of links in a food web enhance the dominance of species within a natural complex. If the number of one host herbivore would decrease, then the alternative hosts would contribute to maintain the natural enemy populations, which lead to a successful biological control (Landis et al. 2000).

$$Connectance = S * (S - 1)/2$$

Where: S = number of all species (host plant, host herbivore, and primary parasitoids) in the food web

2.3. Management intensity and orchard features

We explored the targeted orchards in two different management types such as managed orchards (integrated, intensive, and organic) and Streuobst (semi-abandoned orchard).

Organic management type occurs where the appropriate management practices are executed by living and natural resources. The precautionary and preventive measures are done according to the risk assessment analysis. All genetically modified plants are excluded from this type of management. The external inputs should be restricted to naturally based substances. In cases that the biological substances are not available in market or the impact of biological agents are not clear to the environment, natural chemical products may be applied. The definition and features of organic management adapt to local conditions.

The intensive management type is rather conventional type (highly human manipulated environment) using large amount of labour and capital in a small-scale orchard using intensified application of insecticide, fungicides and herbicides to produce significantly greater crop yield in a commercial aspect. The bio-pesticides apply no role in the orchard management plan. The diversification and mixture of different plant species and cultivars are minimized per unit.

Integrated control is a pest management system that, in context of the associated environment and the population dynamics of the pest species, uses all suitable techniques and methods in as compatible as possible and maintains the pest population densities below the economic injury level. It is not a simple juxtaposition or superposition of two control techniques (such as chemical (conventional) and biological control) but the integration of all the management techniques suited to the natural regulation and limiting factors of the environment. It is similar to the quality of forest environment, which enjoys a richer diversity of fruit trees and multi-purpose plants (e.g. flowering plants) growing together improving an orchard with small inputs of synthetic and bio- pesticide application and higher productivity by a sustainable management in a large-scale orchard.

Streuobst management (semi-abandoned orchards) applies where almost no human perturbation exists and can be extended in small to large-scale orchard with minor intensity of bio-insecticides and treatments. Usually, these orchards are not treated with pesticides. The diversification of fruit tree cultivars and non-profit plant species is in part similar to the quality of intact environments (e.g. forest). The intensification of labour and capital is highly decreased and commercial aspects are not taken into account.

Due to the fact that in managed orchards any lepidopterous pest is controlled by chemical or biological insecticides, and in organic orchards by natural (plant origin) and biological insecticides, the probability to find tortricid pests and, particularly, their parasitoids was far too low for a reliable study, except the few locations mentioned below. Although the number of orchards of different management intensity is not balanced and also differs between regions, statistical analysis is possible, taking the managed orchards as reference to compare with Streuobst as more or less conserved habitats with low anthropogenic input.

Table 2.2. Different management intensity and orchard attributes

| **Management type** | **Intensity application** | | **Area / scale** | **Plant diversification** | **Labour / capital use** |
|---|---|---|---|---|---|
| | **Synthetic pesticides** | **Bio pesticides** | | | |
| Organic | Low | Low/ high | Small or Large | High | Low |
| Integrated | Moderate | Moderate | Large | High | Moderate |
| Intensive | High | High | Small | Low | High |
| Streuobst | No inputs | Low | Small or Large | High | Low |

## 2.4. Study sites

### 2.4.1. Baden-Württemberg

*Denzlingen*

This is a municipality in the district of Emmendingen. It is situated 8 km north of Freiburg and geographically located in 48°04'08.55"N and 7º53'20.63"E elevated 238 m above sea level (Fig. 2.1.). The apple orchards, which sampling occurred was geographically located in 48º03'46.87"N and 7º52'31.79"E, and were differentiated into three types of orchard management such as intensive (conventional crop protection inputs), Organic (organic farming with natural pesticides inputs) and streuobst (minimal natural pesticides inputs). The area was nearly flat and nearby the orchards other agricultural crops were cultivated such as palm, peach, ornamental roses, berries and wax beans. The apple cultivars in intensive management were rather young but the trees in the other managements were rather old with high branches which pruning was not occurred. The apple cultivars were thirteen species such as Berlepsch, Bohnapfel, Boskoop, Champagner Renette, Golden Delicious, Glockenapfel, Goldparmäne, Gravensteiner, Idared, Jonagold, Jonathan, Martinsapfel, and Ontario.

*Emmendingen*

This is a town located at the Elz River, 14 km north of Freiburg in Breisgau. The area of this town is 33.8 $km^2$, which is geographically located in 48º07'01.53"N and 7º51'14.06"E elevated 207 m from the sea level. The apple orchard was located on one side of a hill steep geographically located in 48º06'59.47"N and 7º53'55.91"E elevated 300 m above the sea level (Fig. 2.2.). In comparison with the other orchards sampled in Baden-Württemberg, this orchard enjoyed thirty-seven diversified apple cultivars. The apple cultivars found were Antonowka, Aujäger, Bittenfelder, Blumberger Langstiel, Brauner Matapfel, Danziger Kantapfel, Dürbheimer Sämling, Erbachhofer Weinapfel, Everiner, Gartenmeister Simon, Gehres Rambour, Gewürzluikenapfel, Grahams Jubiläumsapfel, Grüner Gülderling, Hauxapfel, Himbeerapfel, Horneburger Pfannkuchenapfel, Jakob Fischer, Jubeljahrapfel, Kaiser-Wilhelm-Apfel, Lanes Prinz Albert, Lausitzer Nelkenapfel, Leipferdinger Langstiel, Prinzenapfel, Purpurroter Cousinot, Rheinischer Bohnapfel, Roter Bellefleur, Schöner aus Nordhausen, Schwarzwälder Renette, Sonnenwirtsapfel, Sudetenrenette, Thurgauer Weinapfel, Trenkle Sämling, Ulmer Polizeiapfel, Unadinger Sämling, Wiltshire, Yartings Kracher. The orchard was managed as Streuobst (minimal bio-chemical inputs).

*Neuhausen*

Neuhausen auf den Fildern is a municipality in the district of Esslingen in southern Germany, which is located 13 $km^2$ southeast of Stuttgart. This area is geographically located 48º40'55.56"N and 9º16'32.97"E, elevated 326 m above the sea level (Fig. 2.3.). The apple orchard managed Streuobst and is located in 48º40'27.09"N and 9º17'00.30"E, elevated 363 m above the sea level. The area is covered with jungle trees and mixture of private orchards in the region.

*Scharnhausen*

This location is a district of the city of Ostfildern, which is geographically in 48º42'28.26"N and 9º15'46.36"E, elevated 307 m above the sea level (Fig. 2.4.). The apple orchard is managed as Streuobst. Other fruit trees such as palm and pear exist in mixture with the apples. The northern west of the orchard on the top of the hill there are jungle trees.

*Plieningen*

This location is the southernmost municipality of Stuttgart, which is 10 km far from the city centre. The area is nearly 13.07 $km^2$ and geographically located in 48º42'28.52"N and 9º11'49.45"E, which elevated 384 m above the sea level (Fig. 2.5.). This region belong different varieties of apple cultivars such as Bittenfelder Sämling, Brettacher, Champagner Renette, Coulons Renette, Cox Orange, Gewürzluiken, Glockenapfel, Goldparmäne, Hohe Wart, Jakob Lebel, Kaiser Wilhelm, Krügers Dickstiel, Maunzenapfel, Rheinischer Krummstiel, Schöner aus Boskoop, Schwaikheimer Rambur, Sonnenwirtsapfel, Spätblühender Tafelapfel, Transparent aus Croncels, Unseldapfel, Welschisner, Zabergäurenette and Coulons Renette.

*Hohenheim research station*

The Hohenheim research Centre is part of the University of Hohenheim and situated north of the borough of Plieningen on the Filder-plains. It is geographically located in 48º42'44.58"N and 9º11'43.63"E and elevated 395 m above the sea level (Fig. 2.6.). Many different cultivars from fruit trees such as apple, pear, palm, sweet cherry, sour cherry and berries exist. There are also many other ornamental plants are cultivated in this centre. The average age of most of the tree cultivated in this research centre is young and usually the trees above their middle age are cut and being substituted with new cultivars. The apple cultivar used to study was Topaz. The orchard management follows the principles of integrated pest control (IPM).

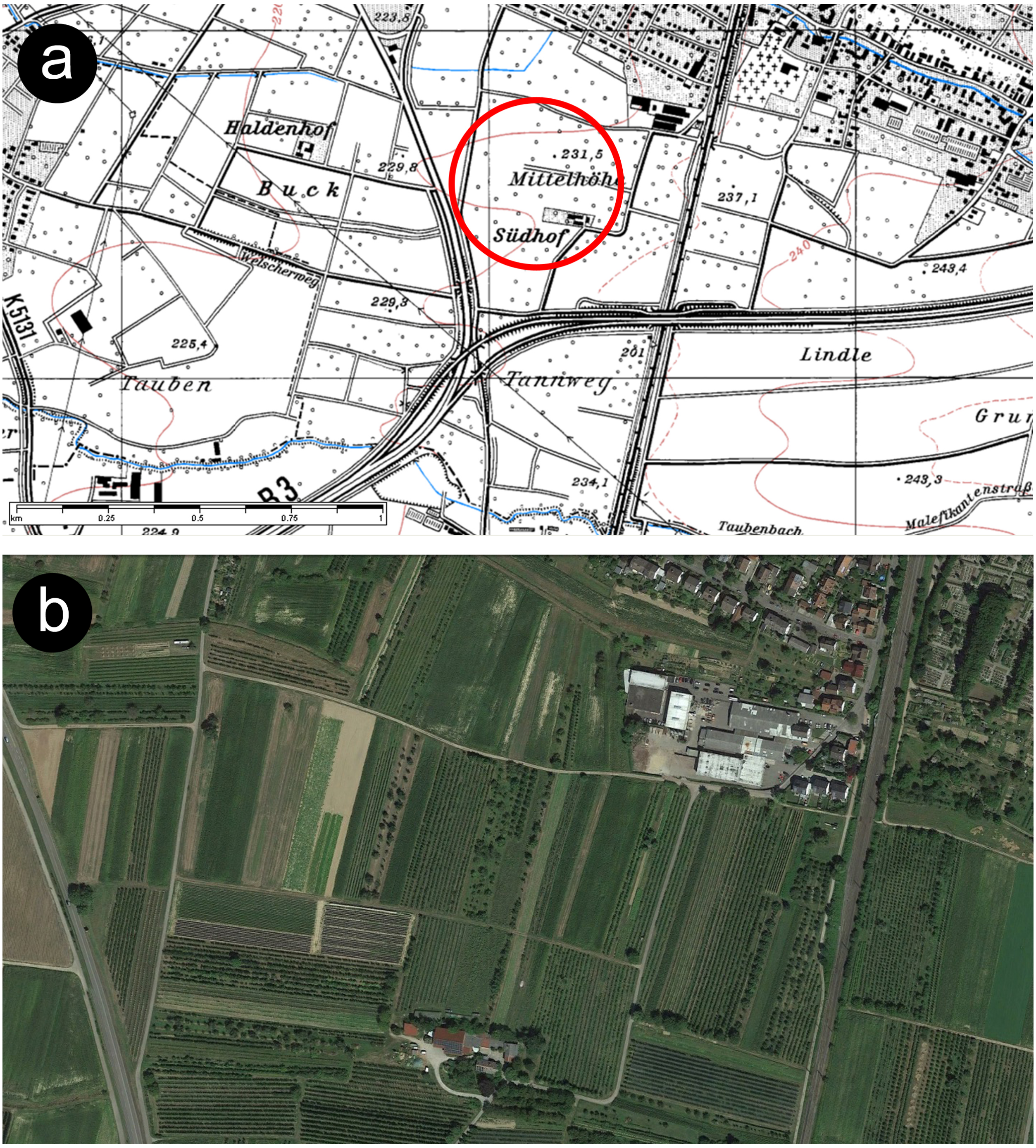


Fig. 2.1. a: map, b: aerial picture. Apple orchard Denzlingen, with three different management of Organic and intensive management, and Streuobst (Google earth, 48º03’46.87”N and 7º52’31.79”E).

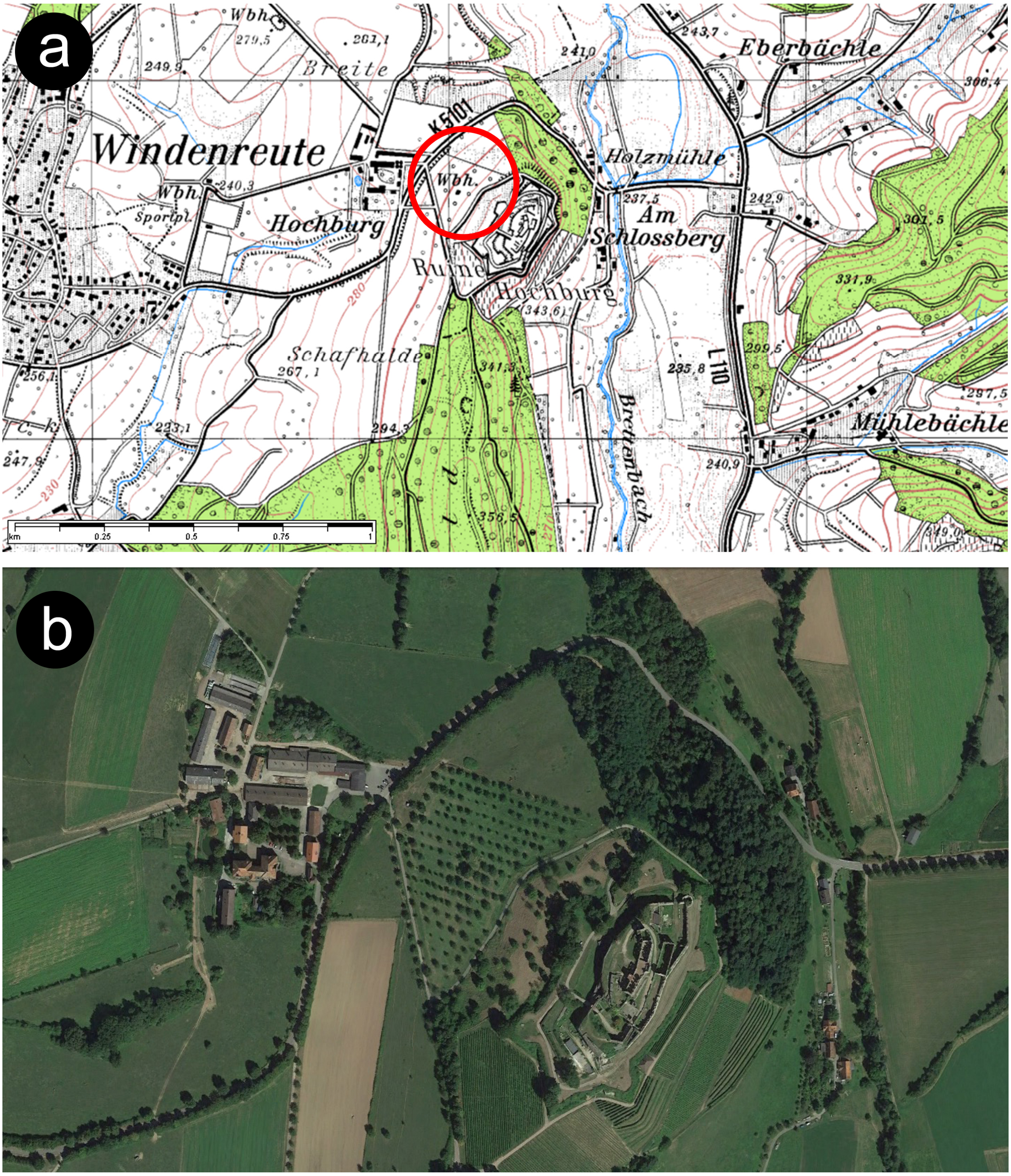


Fig. 2.2. a: map, b: aerial picture. Apple orchard Emmendingen, with Streuobst management (Google earth, scale 48º06'59.47"N and 7º53'55.91"E).


Fig. 2.3. a: map, b: aerial picture. Apple orchard Neuhausen, with Streuobst management (Google earth, 48º40’27.09”N and 9º17’00.30”E).

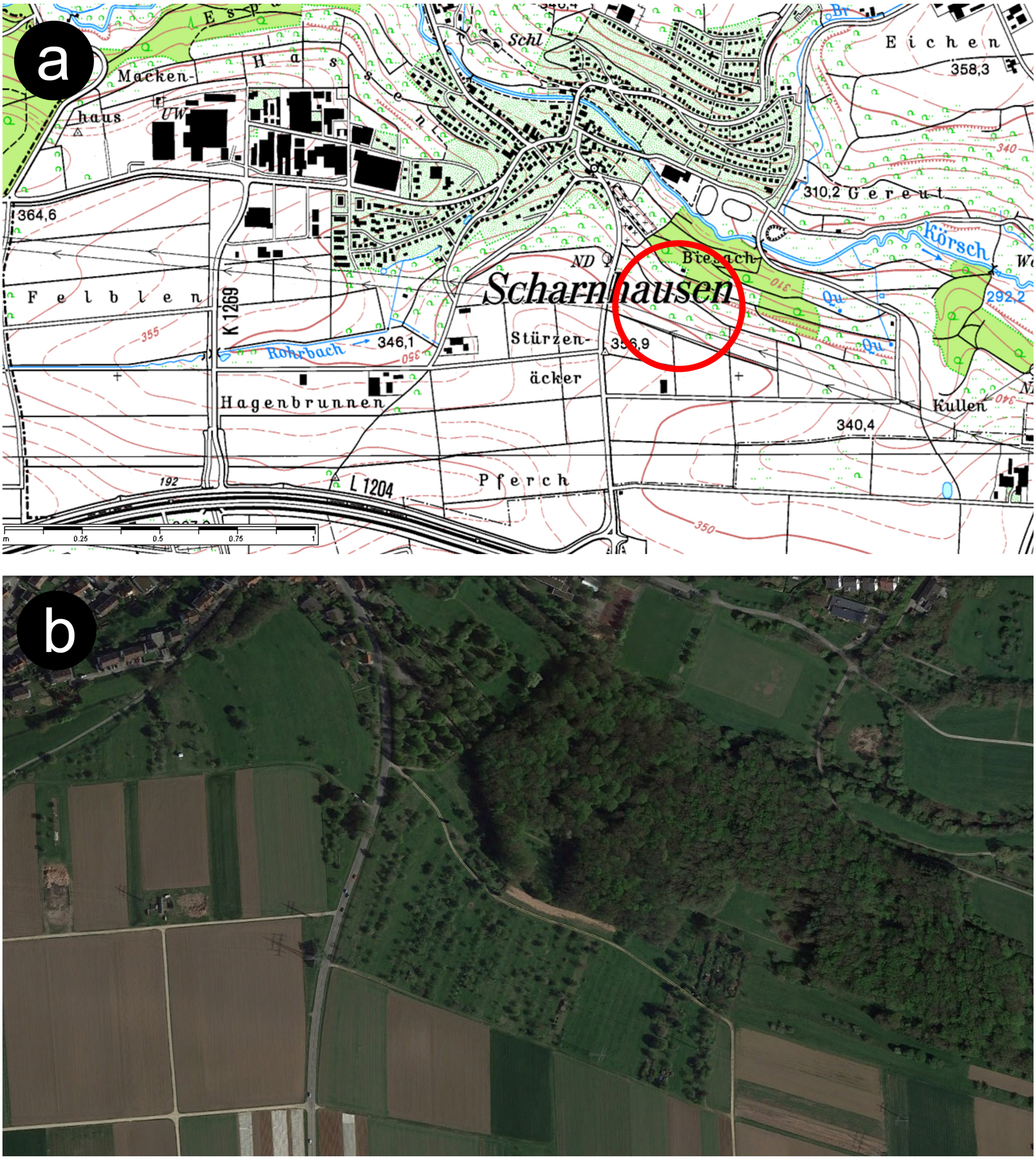


Fig. 2.4. a: map, b: aerial picture. Apple orchard Scharnhausen, with Streuobst management (Google earth, 48º42’28.26”N and 9º15’46.36”E).

*Goldener Grund*

This small apple orchard is located northern direction of main castle building in Hohenheim University, which is geographically 48º43’06.37”N and 9º12’47.89”E, elevated 406 m above the sea level (Fig. 2.7.). The apple cultivars are mixed with pears and most of the trees are old and no pruning has been conducted.

*Rommelshausen*

The orchard is geographically located in 48º48’47.77”N and 9º28’10.60”E, elevated 301 m above the sea level (Fig. 2.8.). The management of the orchard is Streuobst. Other commercial orchards also cover the surrounded area and the dominant apple cultivars in the orchard are Brettacher, Glockenapfel, and Gloster.

*Ilsfeld*

This is a town in the district of Heilbronn in Baden-Württemberg on the outer edge of the Stuttgart metropolitan region. The area of this region is 26.51 $km^2$, which is geographically located in 49º03’19.02”N and 9º14’56.67”E, elevated 228 m above the sea level (Fig. 2.9.). The orchard is located in 49º04’33.00”N and 9º15’24.24”E elevated 273 m above from the sea level. The orchard can be taken as “Streuobst”. The apple was cv. “Brettacher”, which were rather old and pruning had not been done on them.

*Lake Constance (Bodensee)*

This area is known as Bodensee and is the border among Germany, Austria and Switzerland. This region is 536 $km^2$ and geographically located in 47º38’10.82”N and 9º23’21.28”E, elevated 396 above the sea level (Fig. 2.10.). The orchard location was in 47º44’29.32”N and 9º17’34.56”E, elevated 441m above the sea level. The apple cultivars were Brettacher and Boskoop. The age of the trees is a mixture of young and old cultivars. The orchard management was Streuobst.

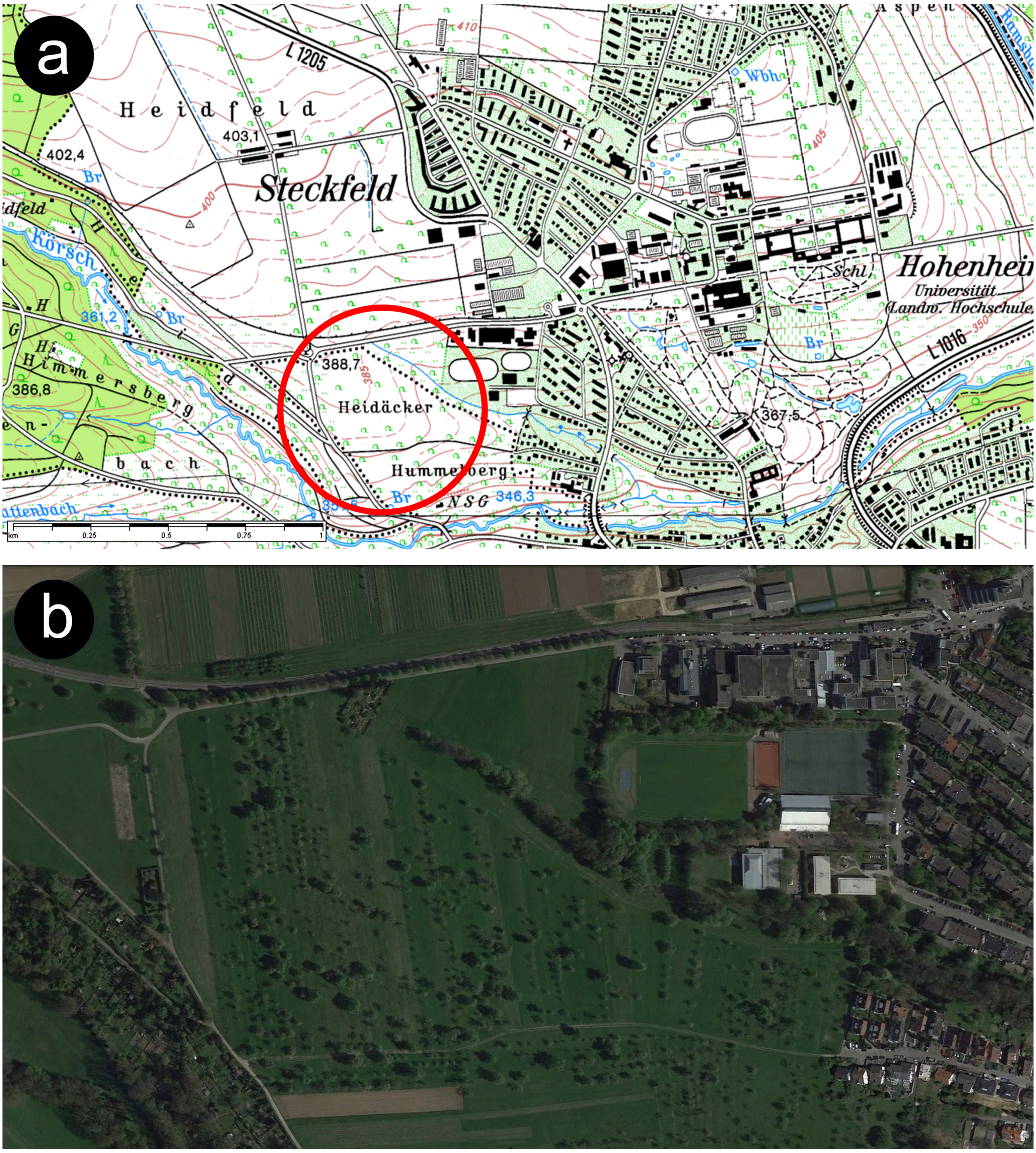


Fig. 2.5. a: map, b: aerial picture. Apple orchard Plieningen-Heidäcker, with Streuobst management (Google earth, 48º42’28.52”N and 9º11’49.45”E).

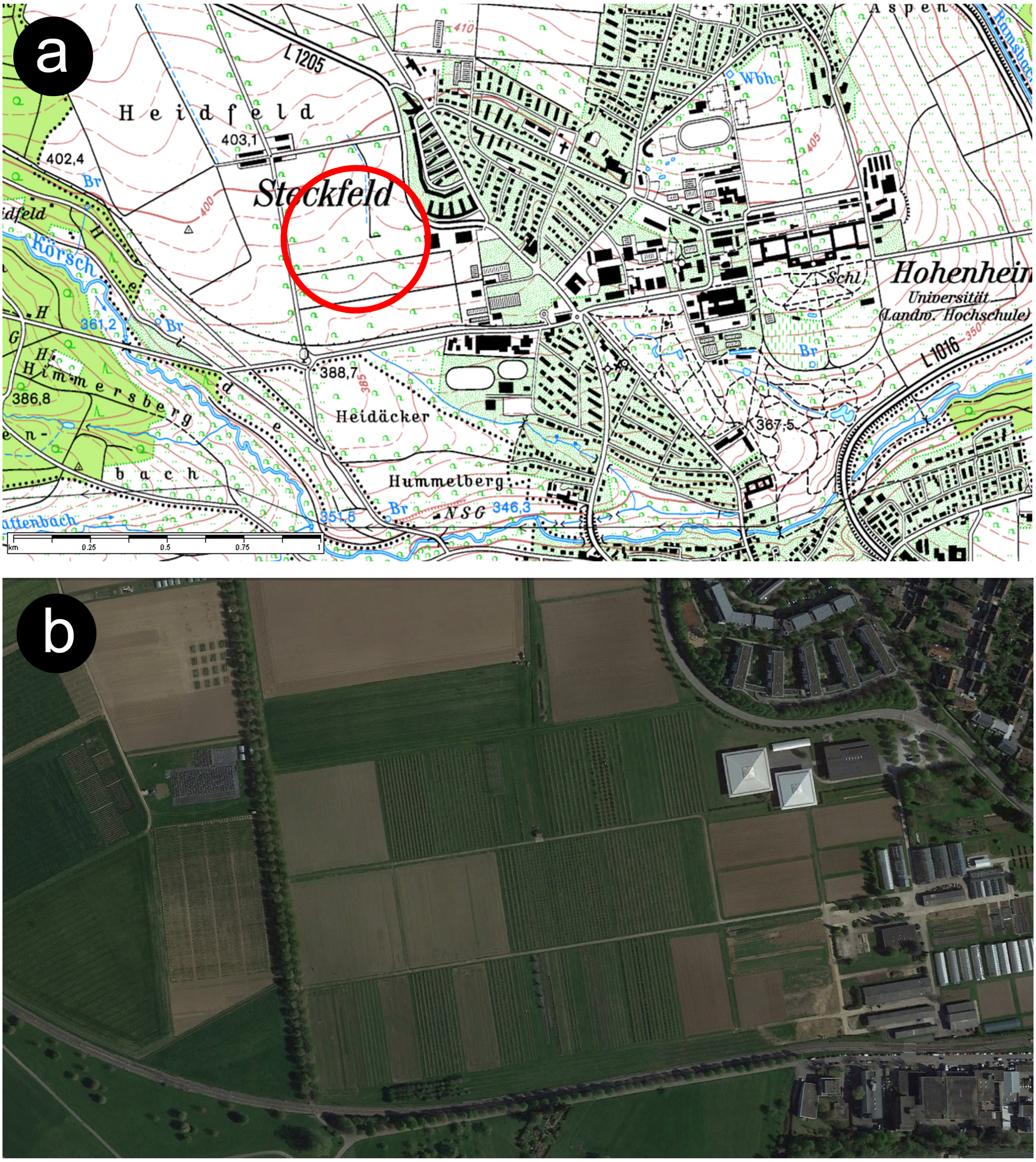


Fig. 2.6. a: map, b: aerial picture. Apple orchard Hohenheim research centre, with integrated management (Google earth, 48º42’44.58”N and 9º11’43.63”E).

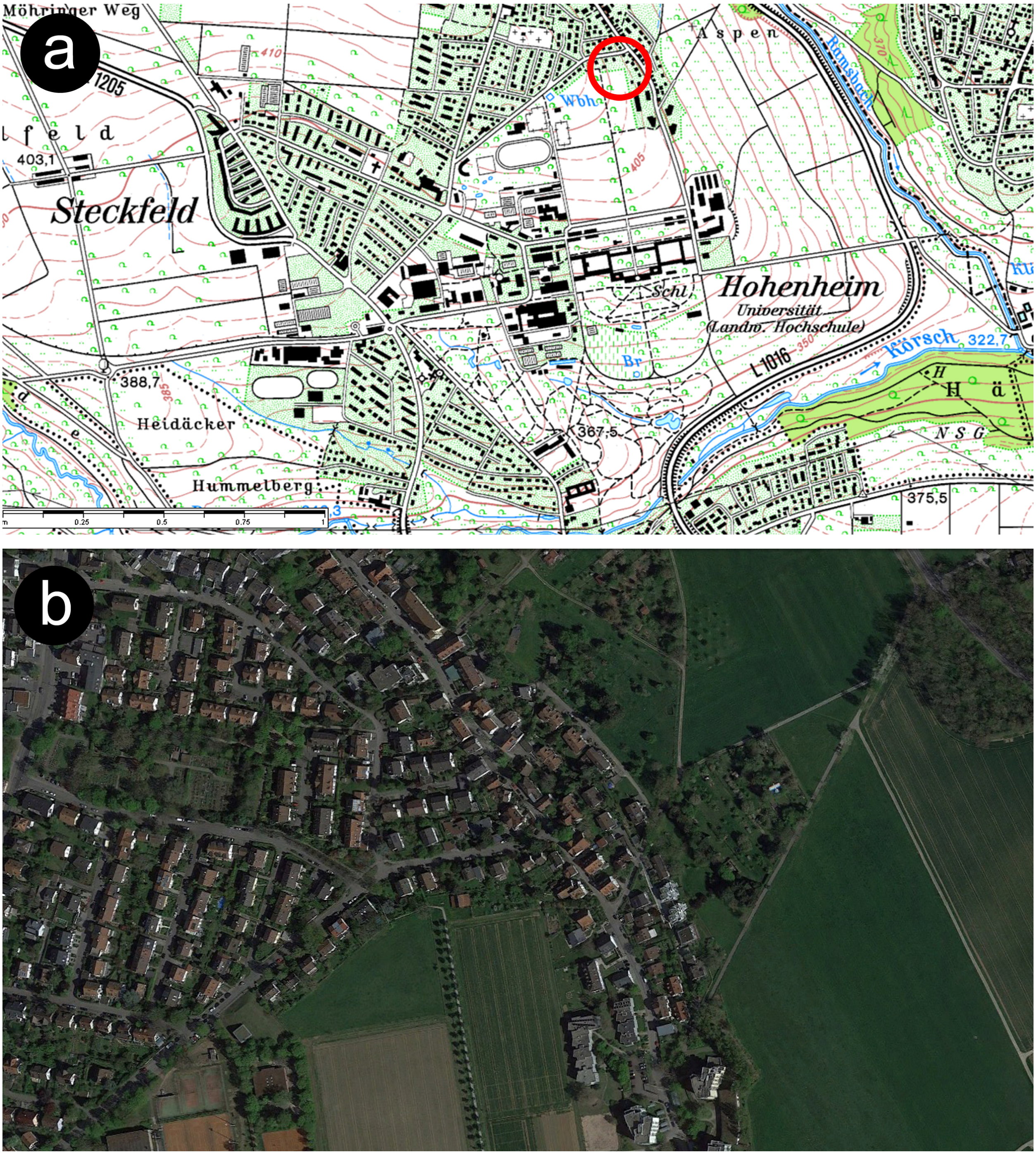


Fig. 2.7. a: map, b: aerial picture. Apple orchard Goldener Grund, with Streuobst management (Google earth, 48º43’05.72”N and 9º12’46.67”E).

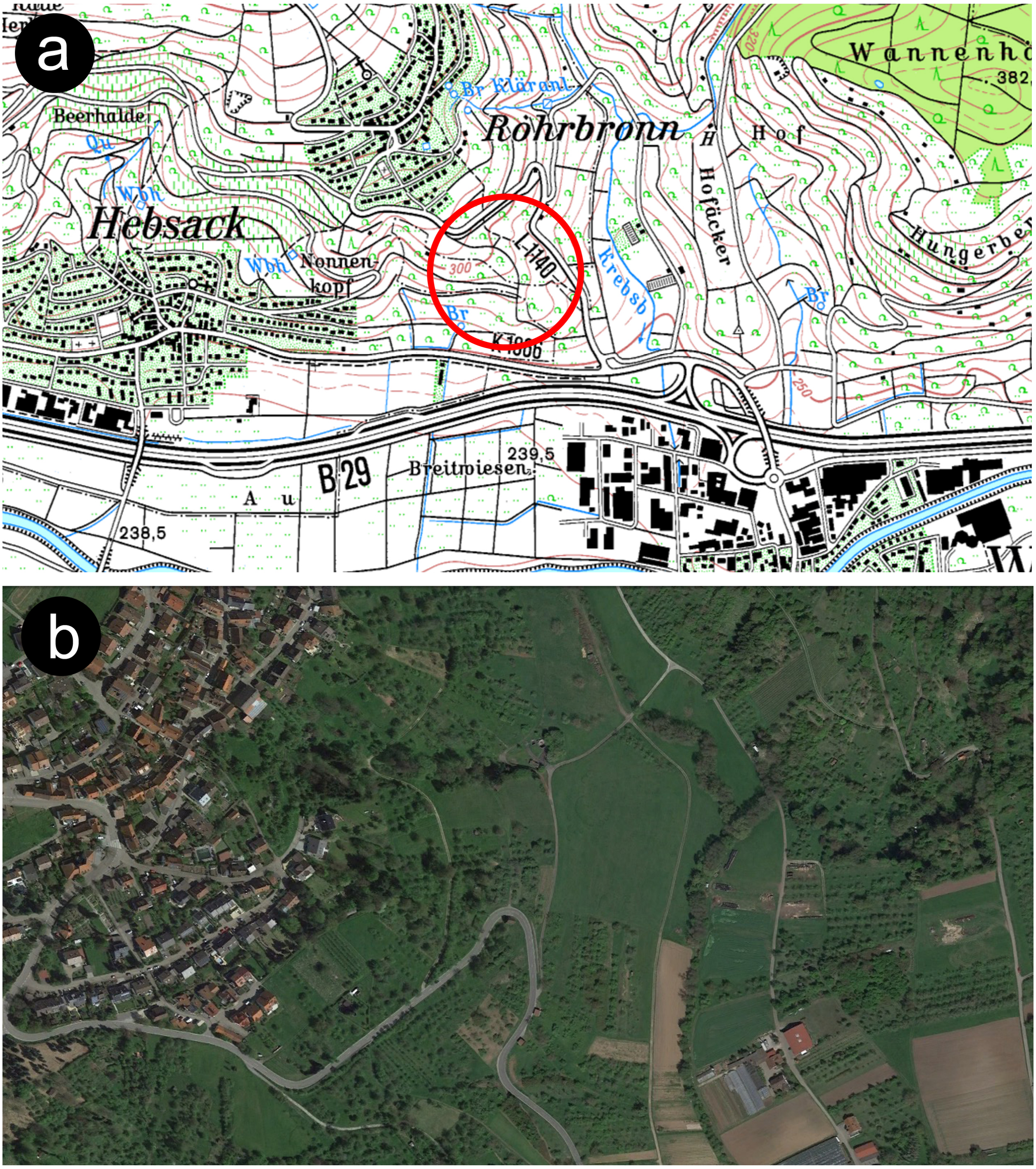


Fig. 2.8. a: map, b: aerial picture. Apple orchard Rommelshausen, with Streuobst management (Google earth, 48º48’47.77”N and 9º28’10.60”E).


Fig. 2.9. a: map, b: aerial picture. Apple orchard Ilsfeld, with Streuobst management (Google earth, 49º04’33.00”N and 9º15’24.24”E).

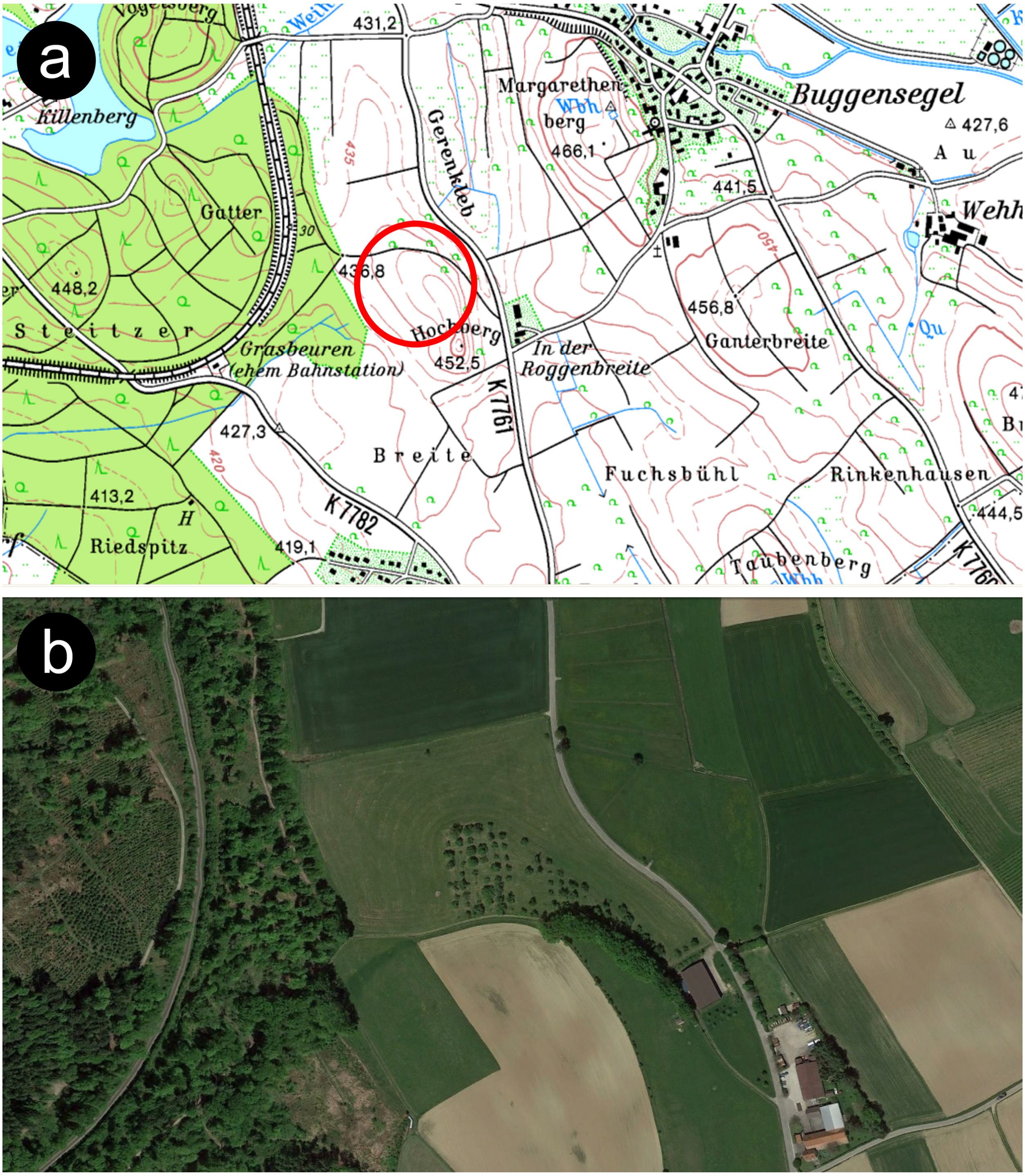


Fig.2.10. a: map, b: aerial picture. Apple orchard Bodensee, with Streuobst management (Google earth, 49º47º44’29.32”N and 9º17’34.56”E).

2.4.2. Study areas for IPM (integrated pest management) strategies in Iran

To assess the *status quo* of crop protection intensity in apple production with emphasis on integrated pest management (IPM), and the social, ecological, and infrastructural background, which may determine crop protection practice on farm, a survey was conducted in different areas of apple production in Iran, i.e. the provinces East and West Azerbaijan, Fars, Isfahan, and Tehran (Fig. 2.11.).

*East-Azerbaijan (A in Fig. 2.11)*

The area of this province is nearly 47,800 km$^2$, geographically located 37º54'12.86"N and 46º16'05.56"E in a mountainous region, which accommodates 4 million inhabitants. Elevation from sea is approximately 1366m. This province has a dry to semi-arid climate and the minimum temperature drops to -15 in winters and reaches to 20 in summers. The annual precipitation is 280 millimeter. Tabriz is capital town in this province. East-Azerbaijan is divided into 19 counties. This survey conducted in different villages such as Begin, Darchikhan, Torbakan and Yam located in Marand region.


Fig. 2.11. Survey provinces in Iran. A: East-Azerbaijan; B: Fars; C: Isfahan; D: Tehran; E: West-Azerbaijan.

*West-Azerbaijan (E in Fig. 2.11.)*

The area of this province is 37,500 km$^2$, geographically located 37º15’56.25”N and 45º00’00.00”E, which accommodates 3,080,000 inhabitants. The capital of this province is Urmia and is divided into 17 counties. The climate of the province is largely influenced by the rainy winds of the Atlantic Ocean and Mediterranean. Cold northern winds affect the province during winter and causes heavy snow. The temperature is lowest in winter -16 and highest in summer 34. The average annual precipitation ranges from 300 to 870 millimeter. This study conducted in two regions Nazlu-chai (villages: Askarabad and Gharehasanlu) and Bakeshlu-chai (villages: Ordushahi and Talmaslu).

*Fars (B in Fig. 2.11.)*

The area of this province is nearly 122,600 km$^2$, geographically located 29º06’15.78”N and 53º02’45.22”E, which accommodates approximately 4.600.000 inhabitants. The climate is varying from north to south and according to that, three distinct regions are identifiable. First is the mountainous area of the north and northwest with moderate cold winter and mild summer. Secondly is the central region with relatively rainy mild winter and hot dry summer. The third region is located in the south and southeast has cold winter with hot summer. The average temperature in Fars province fluctuates from -5 in winters to 32 in summers. Fars province has 23 counties. This survey conducted in different regions such as Abadeh (village: Babasheykh), Ardekan (villages: Poshtekuh, Khoshmakan), Hamayjan (village: Sartali) and Sepidan (village: Margun).

*Isfahan (C in Fig. 2.11.)*

The area of this province is 107,000 km$^2$, geographically located 32º39’16.66”N and 51º40’04.74”E, which accommodates 4,900,000 inhabitants. The capital is Isfahan located in the lush plain of Zayanderud river, at the foothills of the Zagros mountain range. The elevation from sea level is 1,590 meter. The temperature drops to -20 in winters and reaches to maximum 43 in summers. Snow occurs at least once a year. The province is divided into 22 counties. This study was done in 2 regions. Semirom (village: Sabzabad) and Padenaolia (villages: Durjan, Karedan and Valadkhani).

*Tehran (D in Fig. 2.11.)*

The area of this province is 18,800 km$^2$, geographically located 35º41’21.11”N and 51º23’20.30”E, which accommodates 12,200,000 inhabitants. Tehran is the most densely populated province in

Iran. The capital is Tehran and it encompasses 13 counties. The climate in southern east is warm and dry, but in mountain vicinity is cold and semi-humid and in the higher regions is cold with long winter. The temperature fluctuates from -15 C in winters to 30 C in summers. The average annual rainfall is 200 millimetres. Generally, Tehran province has a semi-arid, steppe climate in the south and an alpine climate in the north. The study conducted in region Damavand, which comprised of different villages such as Jaban, Honarlesar, Zibadasht and Khosravan.

### 2.5. Time range

The field investigations were carried out in the years 2011-2015, usually starting in June, when the leaf rollers are abundant in the regions. However, each region could not be surveyed each year (Table 2.3.).

Table 2.3. Time range field investigations between years 2011-2015.

| Locations | Years | | | | |
|---|---|---|---|---|---|
| | 2011 | 2012 | 2013 | 2014 | 2015 |
| 1. Filder-Hohenheim-Goldener Grund Streuobst | | | ● | ● | |
| 2. Filder-Hohenheim-Research station integrated | | ● | ● | | |
| 3. Filder-Neuhausen / Filder - Streuobst | | | | | ● |
| 4. Filder-Plieningen-Streuobst | | ● | ● | ● | ● |
| 5. Filder-Scharnhausen Rathaus-Streuobst | | | | | ● |
| 6. Heilbronn-Ilsfeld-Streuobst | | | | ● | |
| 7. Lake Constance-Überlingen- Streuobst | ● | | | ● | |
| 8. Remstal-Rommelshausen - Streuobst | | | | ● | |
| 9. Upper Rhine valley-Denzlingen-Streuobst | | | | ● | ● |
| 10. Upper Rhine valley-Denzlingen-Organic | | | | ● | ● |
| 11. Upper Rhine valley-Denzlingen-intensive | | | | ● | ● |
| 12. Upper Rhine valley-Emmendingen-Streuobst | | | | | ● |

## 2.6. Questionnaire

A questionnaire survey was conducted among 39 different apple growers in five provinces in Iran where the apple cultivation occurred. The fruit growers were asked to give information on different aspects of general information, farmer information, land use, biodiversity, safety of the farmers and healthy environment, information flow and IPM implementation in regions under study following the table as questionnaire overview (Table 2.4.). See full questionnaire A 2.1. in the appendix.

Table 2.4. Overview of the questionnaire used to assess the status quo of crop protection and integrated pest management.

| **Principals of data structure** | **Brief data description** |
|---|---|
| General information | Region; village; distance to main road; market and extension office |
| Farmer information | Orchard owner; age; family number; level of the education; sex |
| Orchard characteristics | Area of cultivation; cultivars; resistance; soil; fertilizer use; irrigation system |
| Biodiversity | Major pest, disease, weed species and their damage intensity; pesticide application; frequency of pesticide application; |
| Information flow | Extension service visit; source of information on crop protection; pesticide registration issues; |
| IPM implementation | Training on IPM; organizations involved on IPM; reliability of data on IPM; |

## 2.7. Statistical analysis of data

Relevant data were subjected to statistical analysis by the software package JMP© 11.1.1 (2013, SAS Institute Inc.). The statistical procedures used and the statistical core data are given in the legends of tables and figures.

## 3. Results

### 3.1. Field research in Germany

3.1.1. Community structure of tortricids, gelechiids and their larval parasitoids guild in apple orchards in Baden-Württemberg

During five years (2011-2015) total numbers of 7923 healthy caterpillars were collected from different orchards by different management intensity located in Baden-Württemberg, which 692 larvae belonged to leaf rollers (289 larvae were leafrollers and 423 larvae were gelechiids). The number of codling moth was dominant with 7211 individuals. The shares of different species in phytophagous guild among these years were as follows: *Adoxophyes orana* (Fischer von Röslerstamm) (0.03%), *Archips crataegana* Hübner (0.42%), *Archips podana* Scopoli (0.11), *Achips rosana* L. (0.13%), *Achips xylostena* L. (0.23%), *Cydia pomonella* L. (91.01%), *Hedya nubiferana* Haworth (1.17%), *Pandemis cerasana* Hübner (0.03%), *Pandemis heparana* Denis & Schiffermüller (0.04%), *Ptycholoma lecheana* L. (0.01%), *Spilonota ocellana* Denis & Schiffermüller (1.49%) from Tortricidae and *Recurvaria leucatella* Clerck (5.34%) from Gelechiidae.

The total infestation of codling moth larvae found in Streuobst orchard, which spelled to death, was 2243. The natural factors such as fungus, virus and bacteria agents caused the death of 1298, 462 and 483 larvae, respectively. In the locations with intensive management (highly synthetic and Bio- pesticide inputs) the total infested *C. pomonella* were 1483. The infestation agents were identified as fungus, virus and bacteria, which caused the death of 617, 394 and 475 larvae, respectively.

Seven species of leaf rollers *A. orana*, *A. crataegana*, *A. podana*, *A. rosana*, *P. cerasana*, *P. heparana* and *P. lecheana* shared no parasitoids in this study.

Total number of 324 individuals of parasitoid species was found. The species belonged to three families of Hymenoptera. Five species (totally 75 individuals) from Braconidae, 8 species (totally 244 individuals) from Ichneumonidae and 1 species (5 individuals) from Perilampidae were found. The share of different species in community of parasitoid guild between years 2011-2015 in Braconidae in the whole regions under study is as follow: *Agathis pini* Muesbeck (0.31%), *Habrobracon gelechiae* Ashmaed (7.41%), *Ascogaster quadridentata* Wesmael (3.09%), Macrocentrus linearis Nees (2.16%), *Apantheles xanthostigma* Haliday (10,19%). For Ichneumonid species: *Trichomma enecator* Rossi (41.98%), *Pristomerus vulnerator* Panzer (13.27%), *Chorineus funebris* Gravenhost (1.54%), *Liotryphon caudatus* Ratzeburg (4.94%), *Scambus hispae* Harris (7.72%), *Phytodietus polyzonias* Förster (2.47%), Unidentified 1 (1.23%) and Unidentified 2 (2.16%). For the family of Perilampidae: *Perilampus tristis* Mayr (1.54%). The Braconidae, Ichneumonidae and Perilampidae share community percentage of 23.15%, 75.31% and 1.54%, respectively. The location-specific species composition, taxonomic position, and characteristics of some biological data of the larval parasitoids found in this research are given in table (3.1). All natural antagonists were endoparasitoids. All species were solitary except *M. linearis* that was represented as gregarious. The species *P. tristris* (Hym. Perilampidae) was found as primary parasitoids in sites under study while it has also mentioned as secondary parasitoids in other regions of Palearctic.

The host ranges for larval parasitoids and their abundance in different locations are summarized in table (A 3.2.) The broader range of larval parasitoids occurred on *C. pomonella* in comparison with other phytophagous hosts with total number of 8 species. The most common parasitoid was *T. enecator,* which represented 58.93% of all the reared parasitoid specimens. *S. hispae* represented 11.16%, *P. vulnerator* 17.86%, *P. polyzonias* 2.23%, *P. tristis* 2.23%, *L. caudatus* 4.02%, *A. quadridentata* 3.13% and *A. pini* 0.45%. The representation of three different families of Braconidae, Ichneumonidae and Perilampidae on *Cydia pomonella* were 3.57%, 94.2% and 2.23%, respectively. In this research, the most and least efficient species on *C. pomonella* were *T. enecator* Rossi (Ichneumonidae) and *A. pini* (Braconidae), respectively.

A clear difference was observed between different orchards in species abundance and composition (table A 3.2.). The southwestern Baden (Emmendingen), by the Streuobst orchard management indicated five species with high number of individuals (*T. enecator* and *S. hispae*). Denzlingen encompasses two different intensity managements (Organic and intensive), which represents low species richness and low species relative abundance compared with the other locations.

In this study the host range limited on two families of Lepidoptera in all regions and orchard management types. The species *A. pini* was merely found in Lake Constance only once on *C. pomonella*. The species *A. xanthostigma* (Microgasterinae) enjoys a higher range of hosts (tortricids and gelechiids) on four different species, and following species *B. gelechiae*, *M. linearis*, *P. vulnerator* and *L. caudatus* share the host range between tortricids and gelechiids on three different host species. The species *P. tristis* was found as parasitoid on *C. pomonella*, but there is a probability on the role of this species as hyper-parasitoid on *B. gelechiae*. This should be confirmed in future studies.

### 3.1.2. Parasitism rates in different orchard management intensity

A higher parasitization degree was occurred to those orchards where the higher number of larvae was higher. The highest total parasitization rate occurred in Plieningen (2014) and the lowest in Denzlingen (2015) with the Organic management intensity. No host species and relevant parasitoids were found in intensive management intensity so no parasitization occurred. Among tortricids, *C. pomonella* had host for a wide range of different parasitoid species (3 families and 9 species) but the rate of parasitization in comparison to other host species was not that high. The highest parasitization belongs to a commonest parasitoid *T. enecator* in Emmendingen (2015) with Streuobst management intensity. Overall, the highest parasitization rate occurred on *S. ocellana* in Plieningen 2012 by *L. caudatus* and the lowest occurred on *C. pomonella* by two species *A. quadridentata* and *P. tristis* in Plieningen (2014). The largest share in parasitization of phytophaghous host's larvae belonged to Ichneumonidae and it follows by Braconidae and Perilampidae.

The number of host individuals was higher in apple orchards with Streuobst management and according the number of parasitoids was highest in comparison with the rest other three different managements. The highest parasitism rate occurred in integrated following with a minor difference in Streuobst management. The intensive orchards represented no host and relevant parasitoids (table 3.1.).

Table 3.1. Parazitization rate (%) of tortricids and gelechiids species separated by orchard, management intensity and year sampled in 2011-2015.

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Orchard location** | **DEN** | | **DEN** | | **EMM** | | | | | **GOG** | | | | |
| | **Management** | **STR** | | **ORG** | | **STR** | | | | | **STR** | | | | |
| | **Year** | **2015** | | **2015** | | **2015** | | | | | **2014** | | | | |
| | **Parasitoid** | SCAHI | TRIEN | SCAHI | TRIEN | ASCQU | LIOCA | PRIVU | SCAHI | TRIEN | APAXA | BRAGE | MACLI | PHYPO | PRIVU |
| **Host species** | | | | | | | | | | | | | | | |
| **Tortricidae** | | | | | | | | | | | | | | | |
| ARCXYL | | | | | | | | | | | | | | | |
| CYDPOM | | 2.15 | 2.15 | 1.56 | 0.78 | 0.13 | 0.45 | 0.71 | 1.35 | 4.37 | | | | | |
| HEDNUB | | | | | | | | | | | 18.18 | 36.36 | 9.09 | | |
| SPIOCE | | | | | | | | | | | | | | | |
| **Gelechiidae** | | | | | | | | | | | | | | | |
| RECLEU | | | | | | | | | | | 8.47 | | | 1.69 | 1.69 |

Table 3.1. (continued)

| | Orchard location | HOH | | HOH | | ILS | | | LOC | | | LOC | | NEU | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Management** | **ING** | | **ING** | | **STR** | | | **STR** | | | **STR** | | **STR** | |
| | **Year** | **2012** | | **2013** | | **2014** | | | **2011** | | | **2014** | | **2015** | |
| | **Parasitoid** | LIOCA | TRIEN | PHYPO | TRIEN | PRIVU | TRIEN | UNI 1 | AGAPI | PRIVU | TRIEN | LIOCA | TRIEN | APAXA | BRAGE |
| **Host species** | | | | | | | | | | | | | | | |
| **Tortricidae** | | | | | | | | | | | | | | | |
| ARCXYL | | | | | | | | | | | | | | | |
| CYDPOM | | 0.28 | 3.66 | 1.72 | 3.45 | 0.5 | 2 | 0.5 | 0.31 | 0.31 | 0.63 | 0.36 | 0.72 | | |
| HEDNUB | | | | | | | | | | | | | | 9.09 | 18.18 |
| SPIOCE | | | | | | | | | | | | | | | |
| **Gelechiidae** | | | | | | | | | | | | | | | |
| RECLEU | | | | | | | | | | | | | | 6 | |

Table 3.1. (continued)

| | Orchard location | NEU | | | PLI | | | | | PLI | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Management | STR | | | STR | | | | | STR | | | | | |
| | Year | 2015 | | | 2012 | | | | | 2013 | | | | | |
| | Parasitoid | CHOFU | MACLI | PHYPO | APAXA | BRAGE | LIOCA | PRIVU | TRIEN | APAXA | ASCQU | BRAGE | LIOCA | PERTR | PHYPO |
| **Host species** | | | | | | | | | | | | | | | |
| **Tortricidae** | | | | | | | | | | | | | | | |
| ARCXYL | | | | | | 33.33 | | | | 14.29 | | | | | |
| CYDPOM | | | | | | | | 0.94 | 0.94 | | 0.34 | | 0.09 | 0.26 | 0.09 |
| HEDNUB | | | | | | | | | | | | | | | |
| SPIOCE | | | 11.11 | 5.56 | | | 40 | | | | | | | | |
| **Gelechiidae** | | | | | | | | | | | | | | | |
| RECLEU | | 4 | | | 5.71 | 8.57 | | | | 2.6 | | 1.3 | 3.9 | | |

Table 3.1. (continued)

| | Orchard location | PLI | | PLI | | | | | | | | | | PLI | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Management** | **STR** | | **STR** | | | | | | | | | | **STR** | |
| | **Year** | **2013** | | **2014** | | | | | | | | | | **2015** | |
| | **Parasitoid** | PRIVU | TRIEN | APAXA | ASCQU | BRAGE | CHOFU | LIOCA | PERTR | PHYPO | PRIVU | TRIEN | UNI1 | APAXA | ASCQU |
| **Host species** | | | | | | | | | | | | | | | |
| **Tortricidae** | | | | | | | | | | | | | | | |
| ARCXYL | | | | | | | | | | | | | | | |
| CYDPOM | | 1.37 | 1.62 | | 0.06 | | | | 0.06 | 0.12 | 0.24 | 0.8 | 0.18 | | |
| HEDNUB | | | | 9.09 | | 63.64 | | | | | 9.09 | | | 13.04 | |
| SPIOCE | | | | | 16.67 | | | | | | | | | | 2.27 |
| **Gelechiidae** | | | | | | | | | | | | | | | |
| RECLEU | | | | 6.25 | | 2.08 | 2.08 | 2.08 | | | | | | 1.41 | |

Table 3.1. (continued)

| | Orchard location | PLI | | | |
|---|---|---|---|---|---|
| | Management | STR | | | |
| | Year | 2015 | | | |
| | **Parasitoid** | BRAGE | CHOFU | PHYPO | UNI2 |
| **Host species** | | | | | |
| **Tortricidae** | | | | | |
| ARCXYL | | | | | |
| CYDPOM | | | | | |
| HEDNUB | | 4.35 | | | 6.52 |
| SPIOCE | | | | | 4.58 |
| **Gelechiidae** | | | | | |
| RECLEU | | | 1.41 | 1.41 | 10.53 |

Abbreviated names: management intensity: ORG (organic); ING (integrated) and STR (Streuobst).

Pest names: ARCXYL (*Archips xylostena*); CYDPOM (*Cydia pomonella*); HEDNUB (*Hedya nubifera*); SPIOCE (*Spilonota ocellana*) and RECLEU (*Recurvaria leucatella*).

Parasitoid names: AGAPI (*A. pini*); APAXA (*A. xanthostigma*); ASCQU (*A. quadridentata*); BRAGE (*B. gelechiae*); MACLI (*M. linearis*); CHOFU (*C. funebris*); LIOCA (*L. caudatus*); PHYPO (*Ph. polyzonias*); PRIVU (*P. vulnerator*); SCAHI (*S. hispae*); TRIEN (*T. enecator*); UNI1 (*Unidentified 1*); UNI2 (*Unidentified 2*) and PERTR (*Perilampus tristis*).

Table 3.2. Rate of parasitism of pestiferous species by management intensity in 2011-2015 in Baden-Württemberg.

| Intensity management | Nr. Host specimens | Nr. Parasitoid specimens | %Parasitism |
|---|---|---|---|
| Organic | 128 | 3 | 2.34 |
| Integrated | 413 | 17 | 4.12 |
| Intensive | 0 | 0 | 0 |
| Streuobst | 7382 | 304 | 4.11 |
| **Total** | **7923** | **324** | |

3.1.3. Host-density dependence of larval-parasitoid species

Four of the most abundant larval parasitoid species were found positive host-density-dependent, whereas two species showed no or a chaotic density-dependency (Table 3.3.). The rest of parasitoid species found were not considered for calculation because of too small numbers.

Table 3.3. Correlations of parasitoid abundance (most abundant species) with host density.

| Parasitoid Species | Equation | $r^2$ | Density dependency |
|---|---|---|---|
| *Apantheles xanthostigma* | 4.3152 – 0.00036*N hosts | 0.0138 | none |
| *Ascogaster quadridentata* | 5.53 +2.77e-5*N hosts | 4.944e-5 | none |
| *Bracon gelechiae* | 2.6475 + 0.002*N hosts | 0.2230 | positive |
| *Liotryphon caudatus* | 0.5801 + 0.0021*N hosts | 0.2918 | positive |
| *Pristomerus vulnerator* | 0.2414 + 0.0061*N hosts | 0.4819 | positive |
| *Trichomma enecator* | -2.0354 + 0.0215*N hosts | 0.4550 | positive |

3.1.4. Food web pattern and connectance

3.1.4.1. Species properties

In all sampling regions the species properties represented as two levels recognized as basal (herbivore pests e.g. tortricids and gelechiids) and consumers (primary parasitoids e.g. Hymenopterans) which had no intermediate and no hyper-parasitoids. In some cases, the hyperparasitism was occasionally observed but their appearance was not enough reliable and we need more sampling effort for such declaration. There were neither loops and nor omnivore found among all the communities.

The more complex species interactions in comparison to the rest of apple orchard managements are related to Streuobst ones, which had no chemical inputs. It provides the situation to preserve more adult flying antagonists and let them to mate and survive. The flowering plants in Streuobst orchards also helps providing subsidiaries for adult parasitoids and provide sustainable food source to prolong their life span and make it more synchronized and harmonious enabling larval parasitoids to be present in a proper biological time for parasitization. In such orchards the overall parasitization rate is higher than what occurred in other managements. The simplest community structure or no communities found in integrated, Organic and intensive management. Such managements accompany with high synthetic chemical inputs, which hinders natural development of larval parasitoid populations. Such apple orchards are unstable and suffer high biodiversity due to human perturbations. The community structure of basal and primary larval parasitoids for the orchards studied in Baden-Württemberg are shown in the following pages and the species code is available in table (3.3. and 3.4.).

Table 3.3. Codes and names of host species.

| Tortricidae | |
|---|---|
| **Codes** | **Phytophagous species** |
| 1 | *A. orana* |
| 2 | *A. crataegana* |
| 3 | *A. podana* |
| 4 | *A. rosana* |
| 5 | *A. xylostena* |
| 6 | *C. pomonella* |
| 7 | *H. nubiferana* |
| 8 | *P. cerasana* |
| 9 | *P. heparana* |
| 10 | *P. lecheana* |
| 11 | *S. ocellana* |

| Gelechiidae | |
|---|---|
| 12 | *R. leucatella* |

Table 3.4. Codes and names of larval parasitoids.

| Braconidae | |
|---|---|
| **Code** | **Antagonistic larval species** |
| 1 | *A. pini* |
| 2 | *A. xanthostigma* |
| 3 | *A. quadridentata* |
| 4 | *B. gelechiae* |
| 5 | *M. linearis* |
| **Ichneumonidae** | |
| 6 | *C. funebris* |
| 7 | *L. caudatus* |
| 8 | *P. polyzonias* |
| 9 | *P. vulnerator* |
| 10 | *S. hispae* |
| 11 | *T. enecator* |
| 12 | Unidentified 1 |
| 13 | Unidentified 2 |
| **Perilampidae** | |
| 14 | *P. tristis* |

### 3.1.4.2. Connectance and quantitative host-parasitoid food webs

Table 3.5. shows the different orchard managements in different years. The management type can affect the connectance values among the interacting species. The three types of managements (managed, organic, and Streuobst) affected the 16 food webs and the trophic links varies from 2 to 14 in different orchard management. The connectance ranges from 6 to 153. The highest connectance values were found in the Streuobst management (e.g. Plieningen 2014) and the least referred to the managed (organic, integrated, and intensive) orchards. The higher value indicated the high number of larval parasitoids existing in Streuobst orchards.

The distribution and existence of native antagonists can be a matter of importance in connectance. Table 3.6. shows how the number of potential partner affiliations vary through hosts in Middle Europa (Germany). There is no affiliation record for the species *A. podana* and highly connected host species, *C. pomonella*, is representative by nearly 228 different parasitoid's species. Although these records are limited to superfamilies such as Ichneumonoidae and Chalcidoidae, the number of links through predator species is not included. The literature did not take account three antagonist's species (*A. pini*, *B. gelechiae*, and *C. funebris*), which were found in current study as larval-parasitoids in Baden-Württemberg. In comparison with the beneficial species found, the *A. xanthostigma* enjoys a higher host ranges.

We also depicted the quantitative host-parasitoid food webs along different regions in Baden Württemberg with different management intensity (Fig. 3.1. to 3.16.). For each web, lower bars represent host (larval antagonistic species) abundance and upper bars represent larval parasitoid abundance, drawn at percent scale. Linkage width indicates frequency of each trophic interaction. As summary, the webs show interaction data pooled across orchard management intensity per-site and year basis. Species codes are given in tables 3.3. and 3.4. for both hosts and their relevant parasitoids, respectively.

Table 3.5. Connectance values between host and their natural antagonists for different apple orchards in Baden-Württemberg.

| | DEN | | EMM | GOG | HOH | | ILS | LOC | |
|---|---|---|---|---|---|---|---|---|---|
| | ST | MAG | ST | ST | MAG | | ST | ST | |
| | 2015 | | 2015 | 2014 | 2012 | 2013 | 2014 | 2011 | 2014 |
| Number of host plants (apple) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Number of host species | 1 | 1 | 1 | 10 | 1 | 1 | 1 | 1 | 1 |
| Number of primary parasitoid species | 2 | 2 | 5 | 5 | 2 | 2 | 3 | 3 | 2 |
| Total number of species | 4 | 4 | 7 | 16 | 4 | 4 | 5 | 5 | 4 |
| **Species connections** | **6** | **6** | **21** | **120** | **6** | **6** | **10** | **10** | **6** |

Table 3.5. (continued)

| | NEU | PLI | | | | ROM | SCH |
|---|---|---|---|---|---|---|---|
| | **ST** | **ST** | | | | **ST** | **ST** |
| | **2015** | **2012** | **2013** | **2014** | **2015** | **2014** | **2015** |
| Number of host plants (apple) | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Number of host species | 5 | 7 | 8 | 7 | 8 | 1 | 5 |
| Number of primary parasitoid species | 5 | 5 | 8 | 10 | 6 | 4 | 3 |
| Total number of species | 11 | 13 | 17 | 18 | 15 | 6 | 9 |
| **Species connections** | **55** | **78** | **136** | **153** | **105** | **15** | **36** |

Abbreviated location names: DEN (Denzlingen); EMM (Emmendingen); GOG (Goldener Grund); HOH (Hohenheim); ILS (Ilsfeld); LOC (Lake of Constance); NEU (Neuhausen); PLI (Plieningen); SCH (Scharnhausen).

Abbreviated management intensity: MAG (Managed orchards: organic, integrated, and intensive); and ST (Streuobst).

Table 3.6. Potential parasitoid species reported for the resp. host in Germany (Middle Europe).

| | **Parasitoid species** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Host species** | *A. pini* | *A. xanthostigma* | *A. quadridentata* | *B. gelechiae* | *M. linearis* | *C. funebris* | *L. caudatus* | *Ph. polyzonias* | *P. vulnerator* | *S. hispae* | *T. enecator* | **Total partner af-filiation** |
| *Adoxophyes orana* F. & R. | | X | X | | X | | | | X | | | **82** |
| *Archips crataegana* Hüb. | | X | | | X | | | X | | | | **28** |
| *Archips podana* Scop. | | | | | | | | | | | | **0** |
| *Archips rosana* L. | | X | X | | X | | | X | | X | X | **158** |
| *Archips xylostena* L. | | X | | X | X | | | X | X | | X | **78** |
| *Cydia pomonella* L. | X | X | X | | | | X | | X | X | X | **228** |
| *Hedya nubiferana* Haw. | | X | X | X | X | | | | X | X | | **43** |

Table 3.6. (continued)

| | Parasitoid species | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Host species** | *A. pini* | *A. xanthostigma* | *A. quadridentata* | *B. gelechiae* | *M. linearis* | *C. funebris* | *L. caudatus* | *Ph. Polyzonias* | *P. vulnerator* | *S. hispae* | *T. enecator* | **Total partner af-filiation** |
| *Pandemis cerasana* Hüb. | | | | | | | | | | | | **60** |
| *Pandemis heparana* D. & S. | | X | X | | X | | | X | | | | **69** |
| *Ptycholoma lecheana* L. | | | | | | | | | | | | **30** |
| *Spilonota ocellana* D. & S. | | X | | | X | | | | | | | **120** |
| *Recurvaria leucatella* Cl. | | X | X | X | X | X | | | X | | | **26** |
| **Potential number of links** | **1** | **9** | **6** | **3** | **8** | **1** | **1** | **4** | **5** | **3** | **3** | |

Fig. 3. Host-parasitoid food webs representing % abundance of species involved (species names numbered as in table 3.3. and 3.4.; total length of bars = 100%).

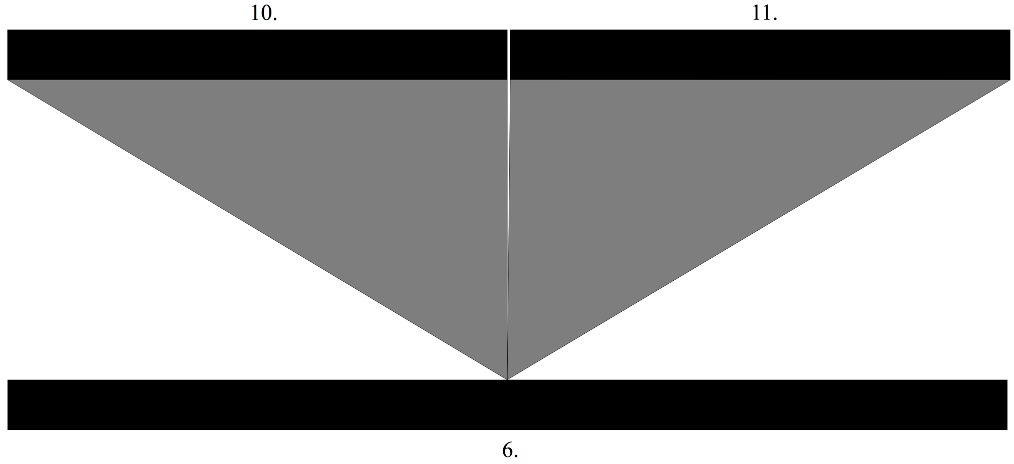


Fig. 3.1. Streuobst apple orchard Denzlingen, year 2015. (Basal species: # 6; Primary parasitoids species: ## 10, 11).

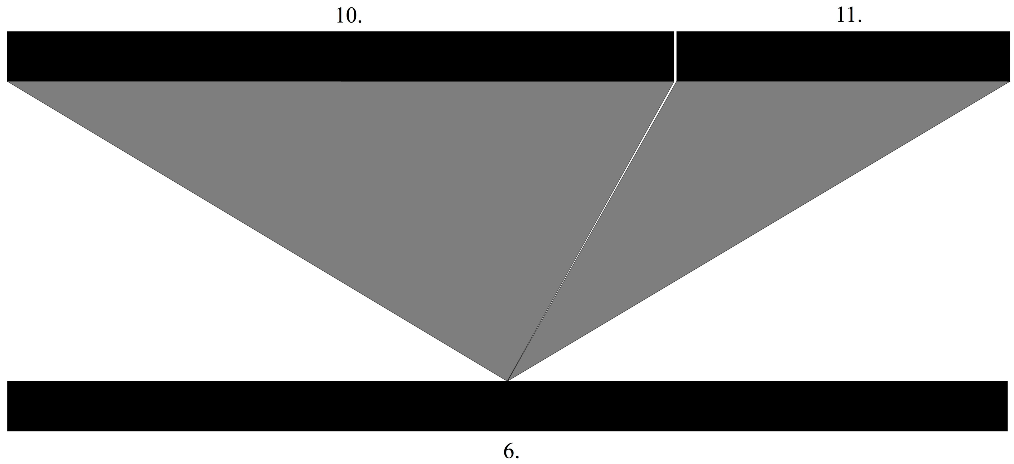


Fig. 3.2. Organic apple orchard Denzlingen, year 2015. (Basal species: # 6; Primary parasitoid species: ## 10, 11).

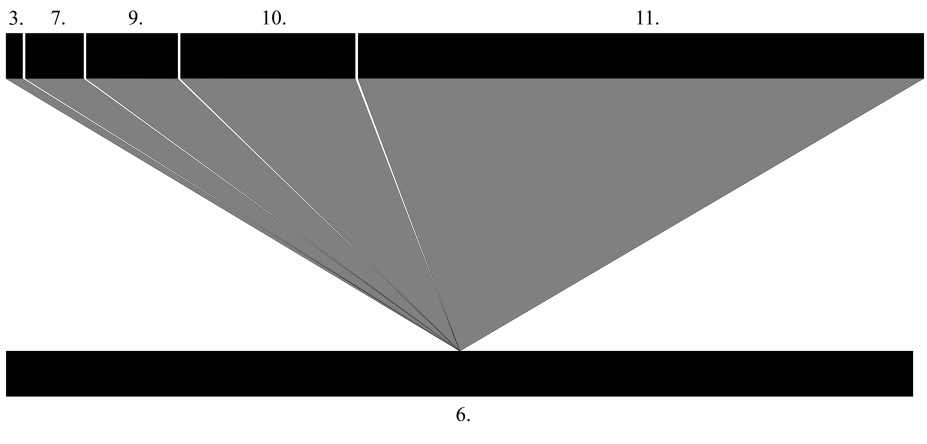


Fig. 3.3. Streuobst apple orchard Emmendigen, year 2015. (Basal species: # 6; Primary parasitoid species: ## 3, 7, 9, 10, 11).

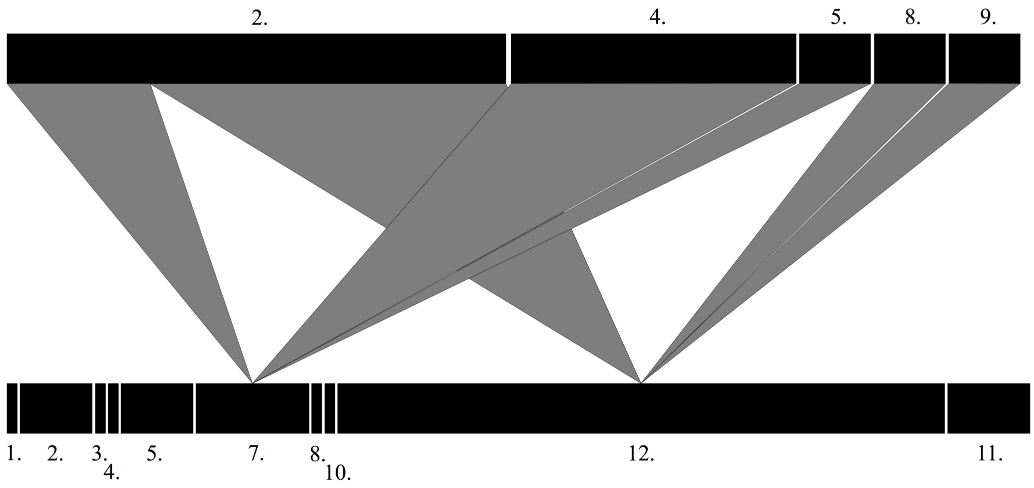


Fig. 3.4. Streuobst apple orchard Goldner Grund, year 2014. (Basal species: ## 1, 2, 3, 4, 5, 7, 8, 10, 12, 11; Primary parasitoid species: ## 2, 4, 5, 8, 9).

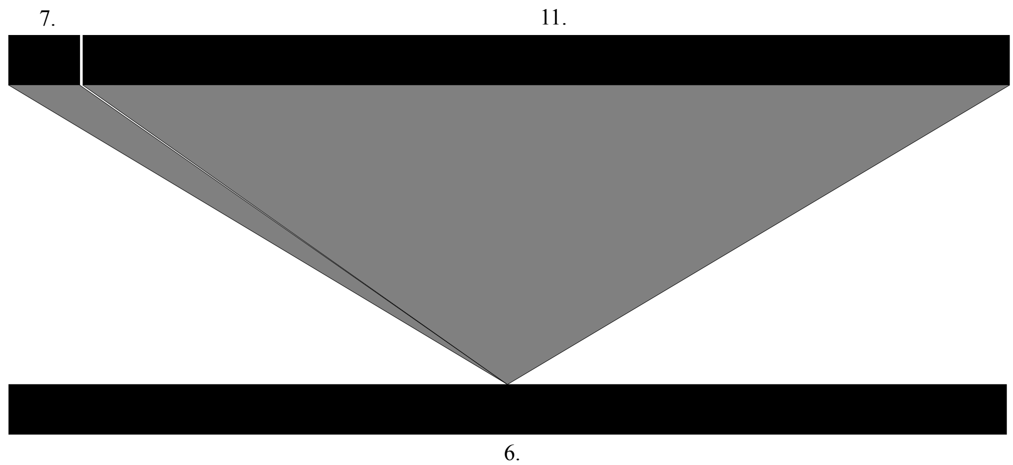


Fig. 3.5. Integrated apple orchard research center Hohenheim, year 2012. (Basal species: # 6; Primary parasitoid species: ## 7, 11).

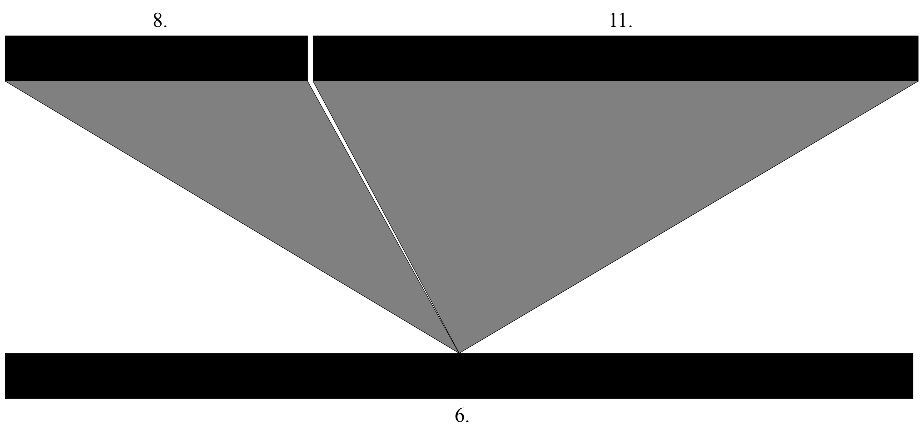


Fig. 3.6. Integrated orchard research center Hohenheim, year 2013. (Basal species: # 6; Primary parasitoid species: ## 8, 10).

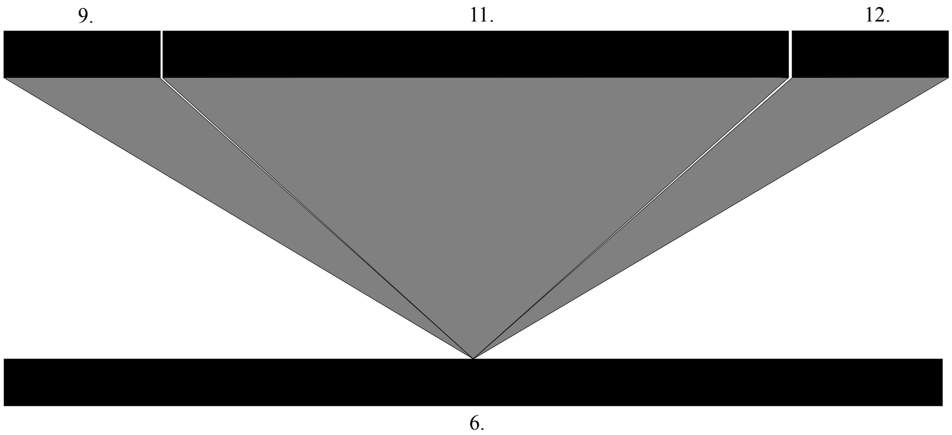


Fig. 3.7. Streuobst apple orchard Ilsfeld, year 2014. (Basal species: # 6; Primary parasitoids species: ## 9, 11, 12).

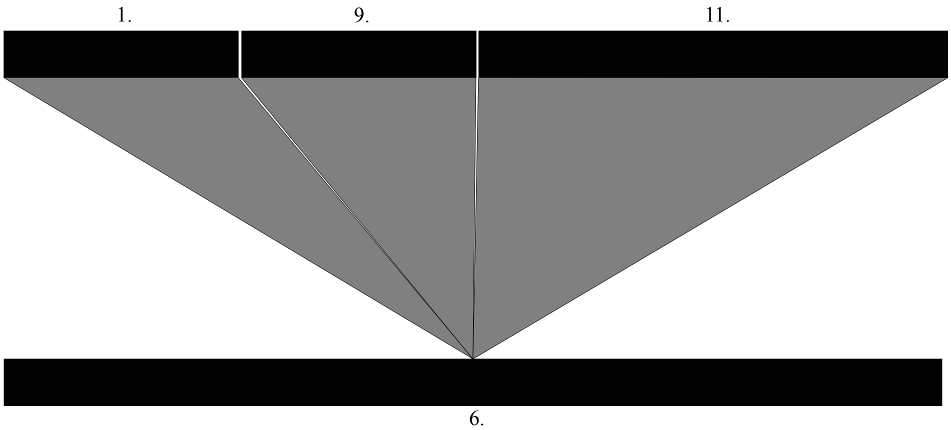


Fig. 3.8. Streuobst apple orchard Lake Constance, year 2011. (Basal species: # 6; Primary parasitoid species: ## 1, 9, 11).

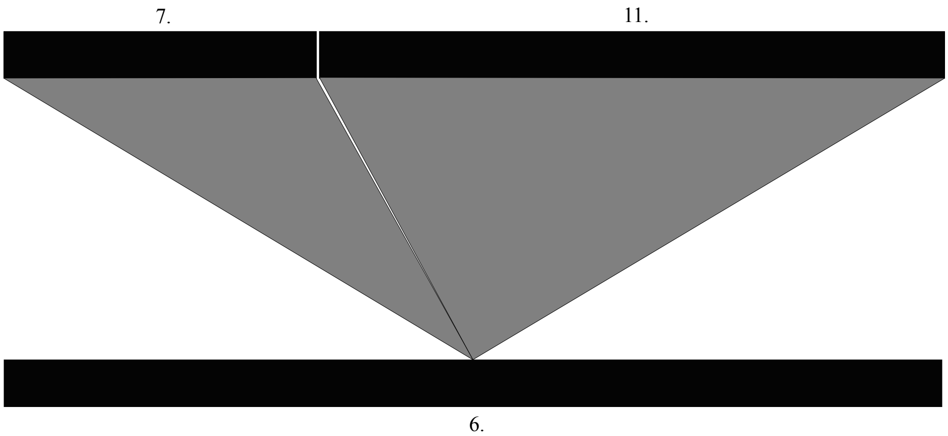


Fig. 3.9. Streuobst apple orchard Lake Constance, year 2014. (Basal species: # 6; Primary parasitoid species: ## 7, 11).

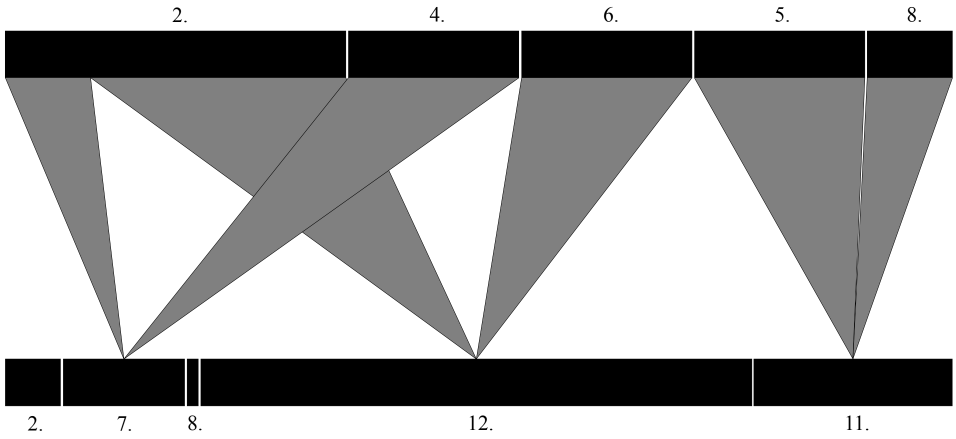


Fig. 3.10. Streuobst apple orchard Neuhausen, year 2015. (Basal species: ## 2, 7, 8, 12, 11; Primary parasitoid species: ## 2, 4, 6, 5, 8).

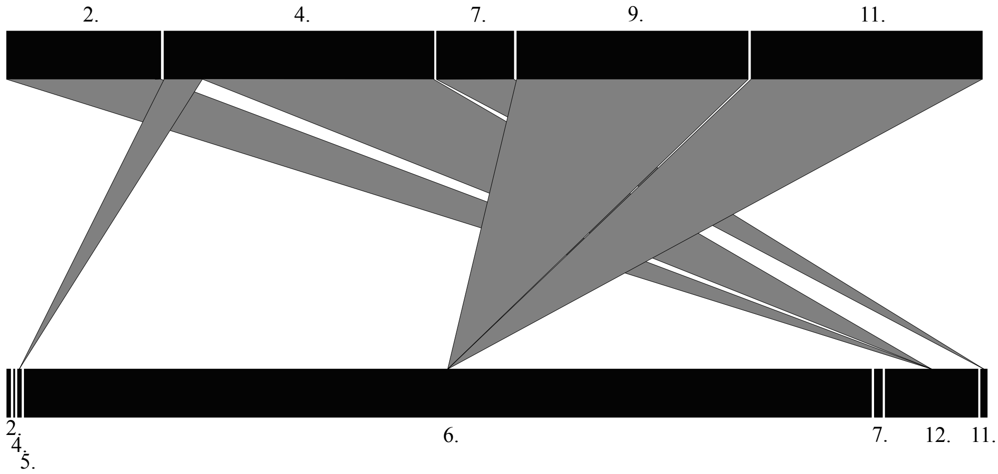


Fig. 3.11. Streuobst apple orchard Plieningen, year 2012. (Basal species: ## 2, 4, 5, 6, 7, 12, 11; ## Primary parasitoid species: ## 2, 4, 7, 9, 11).

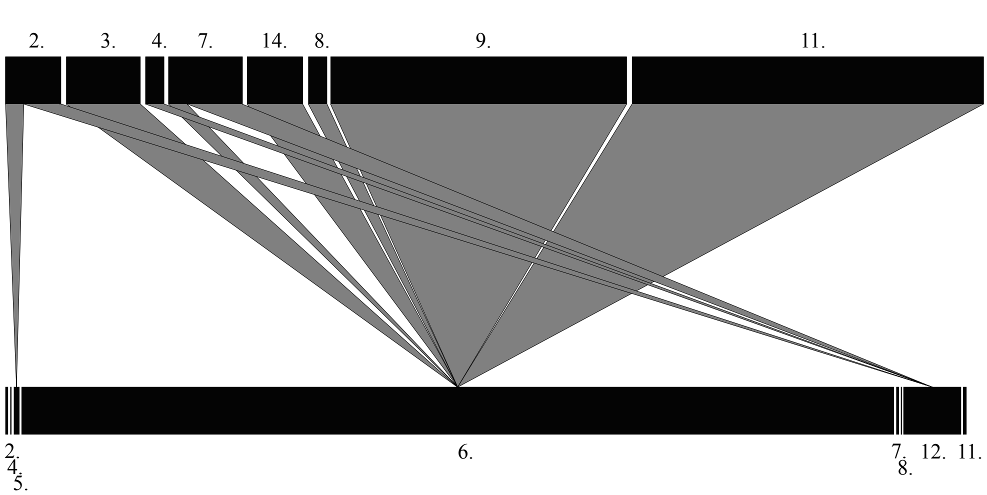


Fig. 3.12. Streuobst apple orchard Plieningen, year 2013. (Basal species: ## 2, 4, 5, 6, 7, 8, 12, 11; Primary parasitoid species: ## 2, 3, 4, 7, 14, 8, 9, 11).

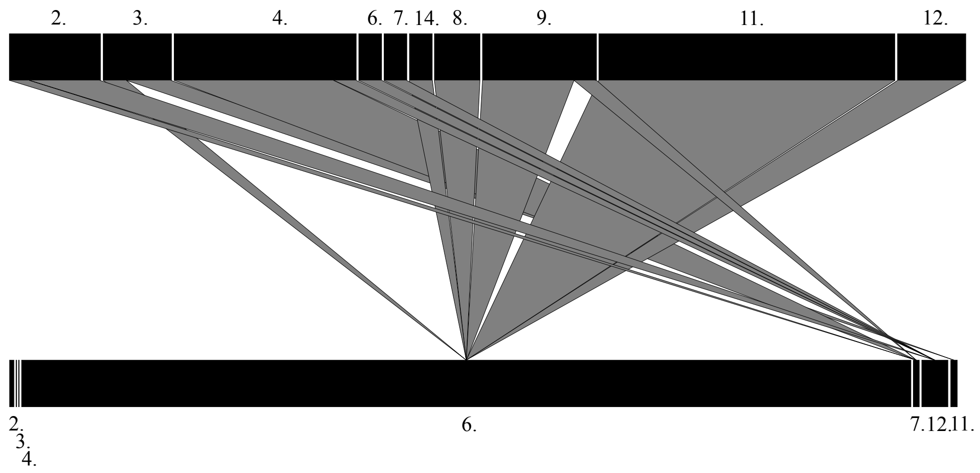


Fig. 3.13. Streuobst apple orchard Plieningen, year 2014. (Basal species: ## 2, 3, 4, 6, 7, 12, 11; Primary parasitoid species: ## 2, 3, 4, 6, 7, 14, 8, 9, 11, 12).

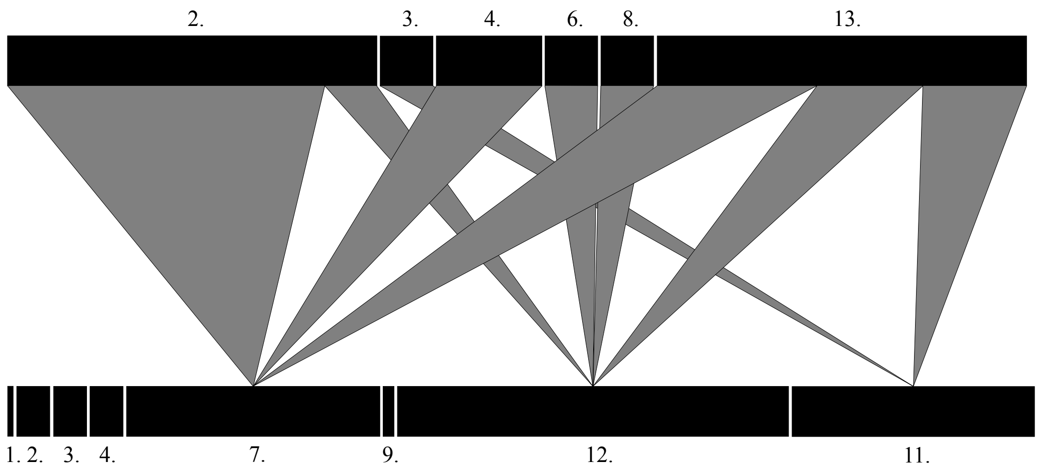


Fig. 3.14. Streuobst apple Plieningen, year 2015. (Basal species: ## 1, 2, 3, 4, 7, 9, 12, 11; Primary parasitoid species: ## 2, 3, 4, 6, 8, 13).

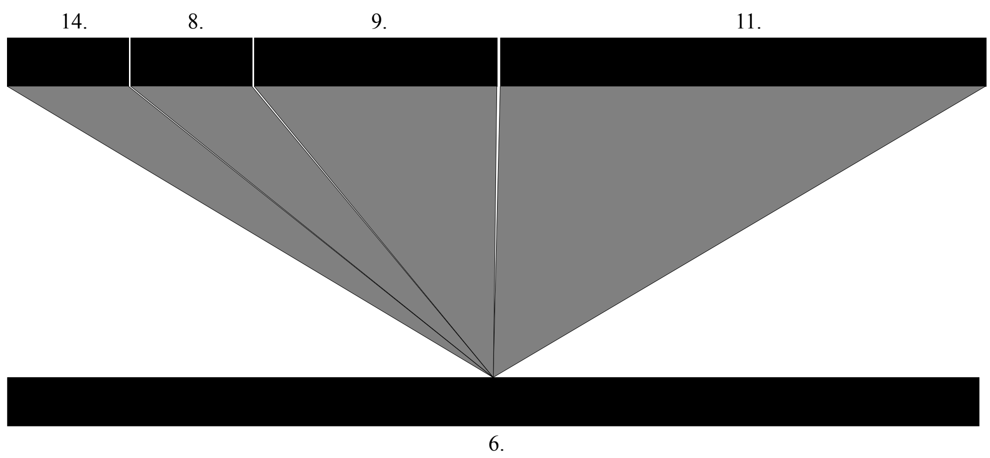


Fig. 3.15. Streuobst apple orchard Rommelshausen, year 2014. (Basal species: # 6; Primary parasitoid species: ## 4, 8, 9, 11).

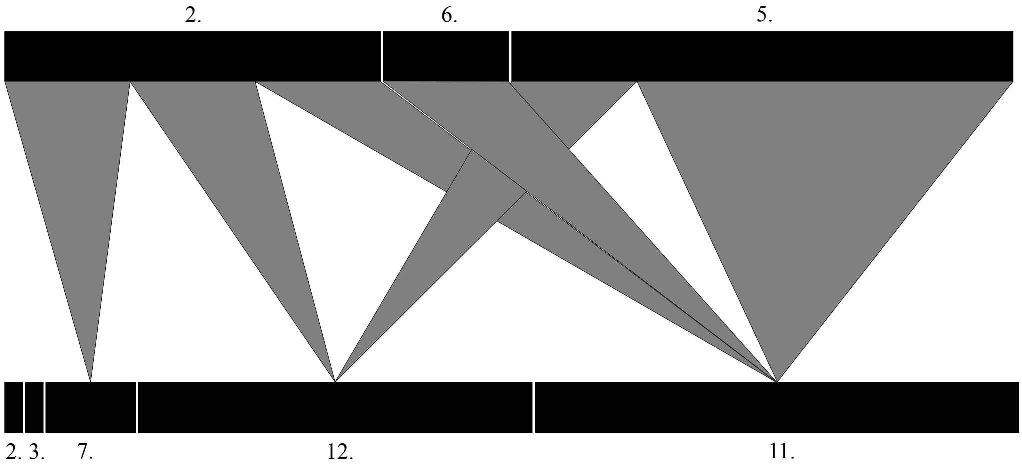


Fig. 3.16. Streuobst apple Scharnhausen, year 2015. (Basal species: ## 2, 3, 7, 12, 11; Primary parasitoid species: ## 2, 6, 5).

3.1.5. Biodiversity indices and different managed and Streuobst apple orchards in Baden-Württemberg

The Shannon and Simpson indices indicate how much a community in a particular region would be even or not. The Simpson index varies between 0 to 1, which indicates how much a community can be biased to even, respectively. The highest biodiversity occurred in locations where there is no chemical input occurs (table 3.7.). We identify them as Streuobst management, e.g. Neuhausen and Scharnhausen. In Denzlingen there were three types of management occurred. In the intensive management the no species found due to high application of synthetic chemicals. Biodiversity did not differ between Streuobst and organic management in Denzlingen. The third most uneven community belongs to Hohenheim (year 2012) where integrated management was in application. Generally, the Streuobst orchards had higher biodiversity indices in comparison with other managements.

Table 3.7. Biodiversity indices through different orchard management in different years in Baden-Württemberg.

| Location | Years | Shannon Wiener | Simpson |
|---|---|---|---|
| Denzlingen (Streuobst) | 2015 | 0.69 | 0.67 |
| Denzlingen (Organic) | 2015 | 0.64 | 0.67 |
| Denzlingen (intensive) | 2015 | 0 | 0 |
| Emmendingen | 2015 | 1.09 | 0.56 |
| Goldener Grund | 2014 | 1.57 | 0.81 |
| Hohenheim | 2012 | 0.26 | 0.14 |
| | 2013 | 0.64 | 0.67 |
| Ilsfeld | 2014 | 0.87 | 0.6 |
| Lake of Constance | 2011 | 1.04 | 0.83 |
| | 2014 | 0.64 | 0.67 |
| Neuhausen | 2015 | 1.72 | 0.89 |
| Plieningen | 2012 | 1.65 | 0.83 |
| | 2013 | 1.70 | 0.76 |
| | 2014 | 2.20 | 0.86 |
| | 2015 | 1.99 | 0.88 |
| Romelshausen | 2014 | 1.21 | 0.75 |
| Scharnhausen | 2015 | 1.67 | 0.89 |

3.1.6. The effect of different management intensity on biodiversity indices in different locations in Baden-Württemberg

In the following analysis, year, region, and management-intensity were chosen as independent variables because these parameters are assumed to have the greatest effect on insect species abundance and composition. The weather conditions may change seriously between the years and, thus, have a direct effect on our results. The regions differ by geographical, climatic, and micro-climatic conditions, which also affect the results, and management intensity is assumed to have direct effects on insects as outlined in the introduction. “Streuobst” vs. commercial apple production and region affect significantly the Shannon-Wiener index (table 3.8.) in different apple orchards. Differences in the type of management in commercial orchards, as a finer distinction, obviously significantly affected the Shannon-Wiener-index (table 3.9.). However, year as independent variable does not significantly affect the diversity index.

Table 3.8. Shannon-Wiener by region, year, and intensity in different apple orchards.

| Source | D.f. | Chi square | P |
|---|---|---|---|
| Region | 4 | 20.88 | 0.0003 |
| Year | 4 | 5.80 | 0.2142 |
| “Streuobst” vs. commercial orchards | 1 | 18.18 | <0.0001 |

(GLM full model; distribution: normal, link: identity, maximum-likelihood; N = 16, L-R-$\chi$2: 33.1643, $P < 0.0001$; d.f. = 9)

Table 3.9. Shannon-Wiener by region, year, and management in different apple orchards.

| Source | D.f. | Chi square | P |
|---|---|---|---|
| Region | 4 | 32.36 | <0.0001 |
| Year | 4 | 6.69 | 0.1528 |
| Management intensity | 3 | 30.98 | <0.0001 |

(GLM full model; distribution: normal, link: identity, maximum-likelihood; N = 16, L-R-$\chi$2: 45.9651, $P < 0.0001$; d.f. = 11)

Management intensity suppressed the effects year and region in the calculation of the Simpson index when apple orchards were coarsely distinguished into “Streuobst” and commercial orchards (-> intensity). A finer distinction of commercial orchards into organic, integrated, and intensive managed orchards revealed significant effects for the factor region and management, and a trend to significance between years. However, these significances should not be overemphasized because of the low number of managed orchards compared to the “Streuobst” orchards (3.10. and 3.11.).

Table 3.10. Simpson-index by region, year, and intensity in apple orchards.

| Source | D.f. | Chi square | P |
|---|---|---|---|
| Region | 4 | 4.62 | 0.3282 |
| Year | 4 | 3.56 | 0.4677 |
| “Streuobst” vs. commercial orchards | 1 | 8.34 | 0.0039 |

(GLM full model; distribution: normal, link: identity, maximum-likelihood; N = 16, L-R-$\chi$2: 17.1841, $P < 0.0459$; d.f. = 9).

Table 3.11. Simpson-index by region, year, and management in apple orchards.

| Source | D.f. | Chi square | P |
|---|---|---|---|
| Region | 4 | 12.51 | 0.0139 |
| Year | 4 | 9.03 | 0.0603 |
| Management intensity | 3 | 27.77 | <0.0001 |

(GLM full model; distribution: normal, link: identity, maximum-likelihood; N = 16, L-R-$X2$: 36.6120, P < 0.0001; d.f. = 11).

Table 3.12. Shannon-Wiener index by different regions through Streuobst management.

| Region | n | Intensity (streuobst) |
|---|---|---|
| Filder | 6 | 1.80 ± 0.09 a |
| Hohenlohe | 1 | 0.87 ± 0 b |
| Lake Constance | 2 | 0.84 ± 0.20 b |
| Remstal | 1 | 1.21 ± 0 ab |
| Rheintal | 2 | 0.89 ± 0.20 b |
| F | | 4,7 |
| d.f. | | 9, 50 |
| P | | 0.0059 |

(Oneway-ANOVA followed by LSD-test: α < 0.05).

Different orchards by the same management type as Streuobst (semi-abandoned) in different regions in baden-Württemberg affected biodiversity index. The orchards located in Filder showed a distinctive assessment compared to the rest of sampled locations (3.12.).

3.1.7. Dominance classification

The dynamic of parasitoid species per orchard through the year 2011 to 2015 were observed. In the year 2011, Streuobst apple orchard located in lake Constance, three parasitoid species *A. pini*, *P. vulnerator*, and *T. enecator* were represented. All species showed a eudominant category (Fig. 3.19.).

Sampling in 2012 extended to Plieningen apple orchard which five species of parasitoids occurred. *L. caudatus* as dominant and *A. xanthostigma*, *B. gelechiae*, *P. vulnerator* and *S. hispae* as eudominant were introduced (Fig. 3.21.).

In 2013, species found in Plieningen were *A. xanthostigma*, *A. quadridentata*, *B. gelechiae, L. caudatus*, *Ph. polyzonias*, *P. vulnerator*, *T. enecator* and *P. tristis*. The dominant classification were as eudominant (68.63%), dominant (27.45%) and recedent (3.92%) (Fig. 3.21. Plieningen).

In 2014, in Goldener Grund, we found five larval parasitoid species. All species found in the orchard were classified 78.57% (*A. xanthostigma*, *B. gelechiae*) as eudominant and 21.43% (*M. linearis*, *Ph. polyzonias* and *P. vulnerator*) as dominant (Fig. 3.18.). In lake of Constance, the number of species found in the same region dropped into two species *Ph. polyzonias* and *T. enecator*, which representing eudominant species (Fig. 3.19. 2014). In Plieningen 10 different larval parasitoid were found. *A. xanthostigma*, *A. quadridentata*, *B. gelechiae*, *C. funebris*, *L. caudatus*, *Ph. polyzonias*, *P. vulnerator*, *T. enecator*, Unidentified 1 and *P. tristis.* Three different classifications were found as eudominant (63.41%), dominant (24.39%) and subdominant (12.2%) in this orchard. In Rommelshausen (Fig. 3.22.), the species were limited to 4 larval parasitoids (*Ph. polyzonias*, *P. vulnerator*, *T. enecator* and *P. tristis*). All species in this orchard were categorized into eudominant.

In 2015, the species found in Emmendingen (Fig. 3.17) representing of five different parasitoids (*A. xanthostigma*, *L. caudatus*, *P. vulnerator*, *S. hispae*, *T. enecator*). They constituted the dominance classification 91.74%, 6.42% and 1.83% as eudominant, dominant and recedent, respectively. In Neuhausen, the eudominant (90.91%) and dominant (9.09%) were identified by five different species (*A. xanthostigma*, *B. gelechiae*, *M. linearis*, *C. funebris* and *Ph. polyzonias*) (Fig. 3.20). In Plieningen, the numbers of larval parasitoids were limited to six (*A. xanthostigma*, *A. quadridentata*, *B. gelechiae*, *C. funebris*, *Ph. polyzonias* and Unidentified 2). Eudominant and dominant classification were 84.21% and 15.79, respectively.

No region showed the subrecendet for dominant classification. The most frequent classifications occurred in eudominant and dominant categories in most locations and years. Subdominant category only represented in apple orchard located in Plieningen 2014. The recedent category was limited to the apple orchards located in Plieningen 2013 and Emmendingen 2015.

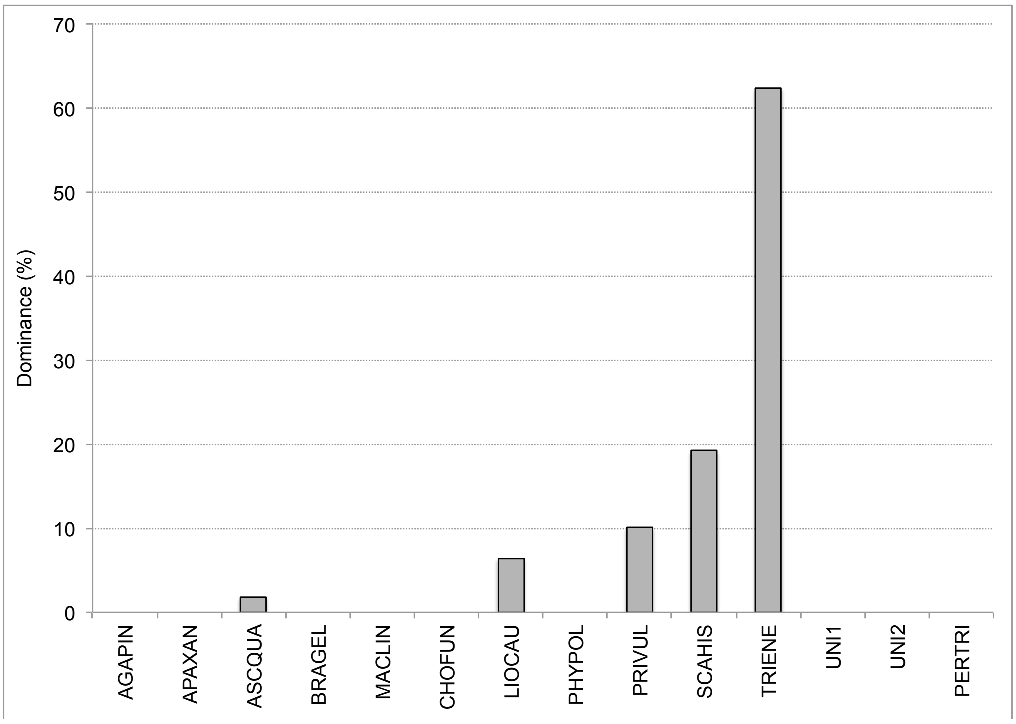


Fig. 3.17. Dominance (%) in apple orchard (Streuobst) located in Emmendingen, 2015.

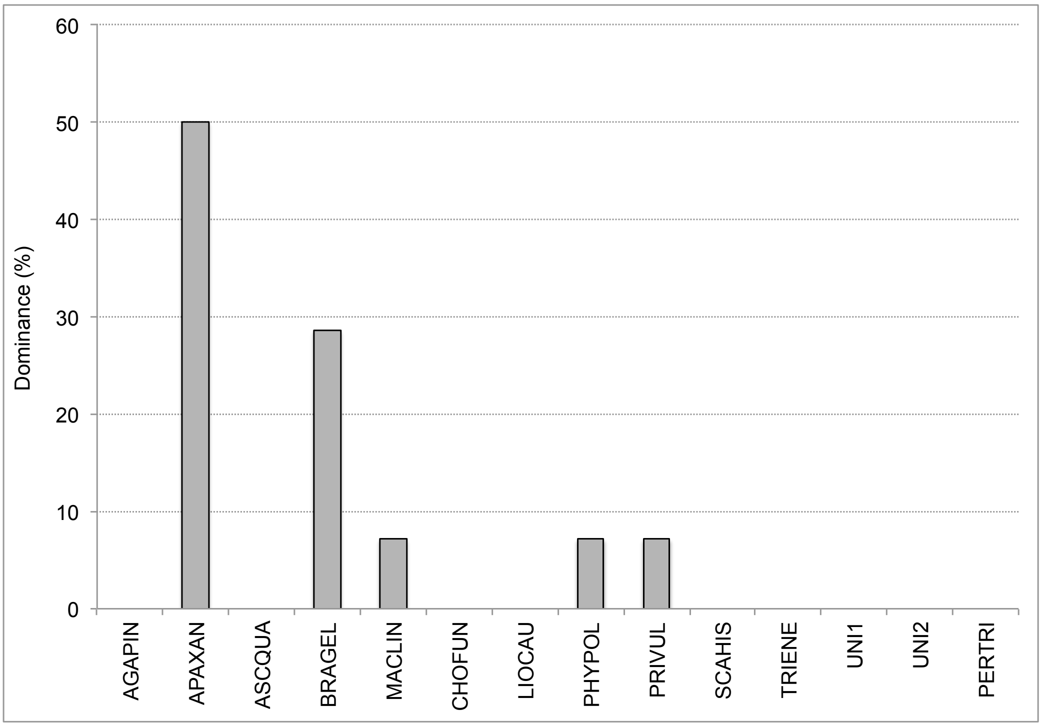


Fig. 3.18. Dominance (%) in apple orchard (Streuobst) located in Goldener Grund, 2014.

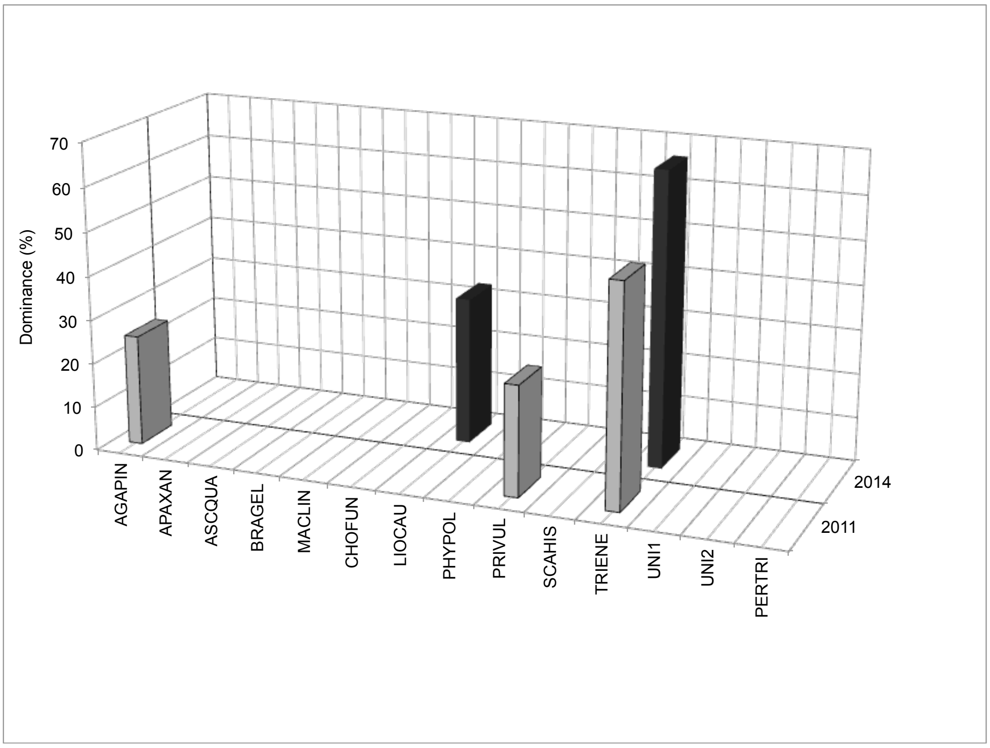


Fig. 3.19. Dominance (%) in apple orchard (Streuobst) located in Lake of Constance for years 2011 and 2014.

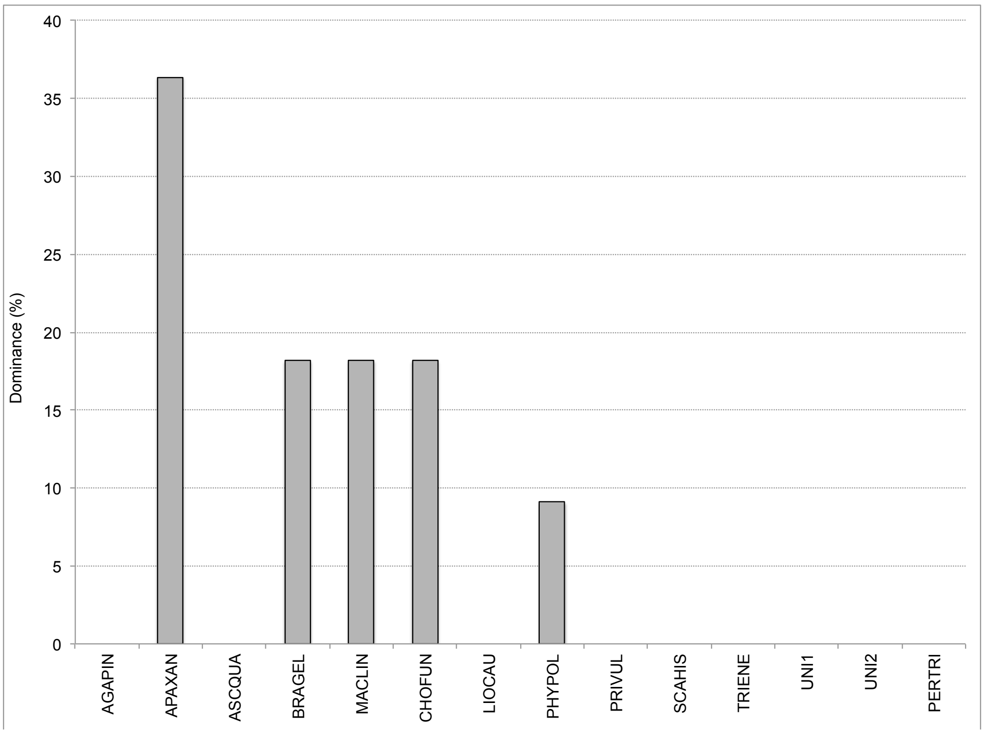


Figure 3.20. Dominance (%) in apple orchard (Streuobst) located in Neuhausen, 2015.

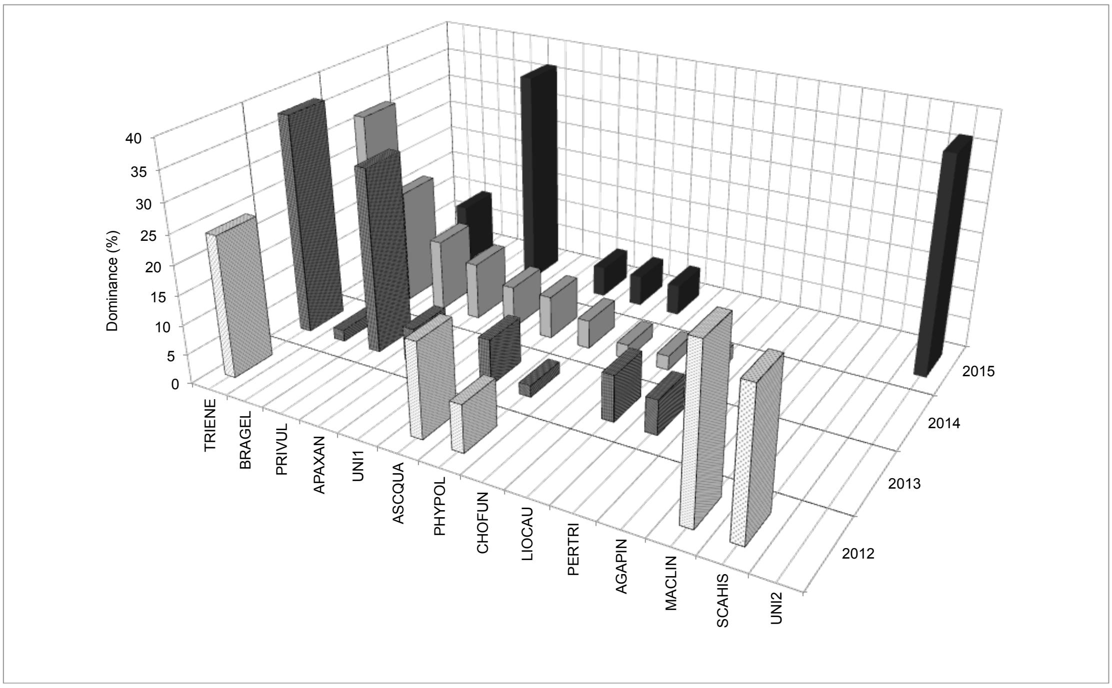


Fig. 3.21. Dominance (%) in apple orchard (Streuobst) located in Plieningen for years 2012, 2013, 2014 and 2015.

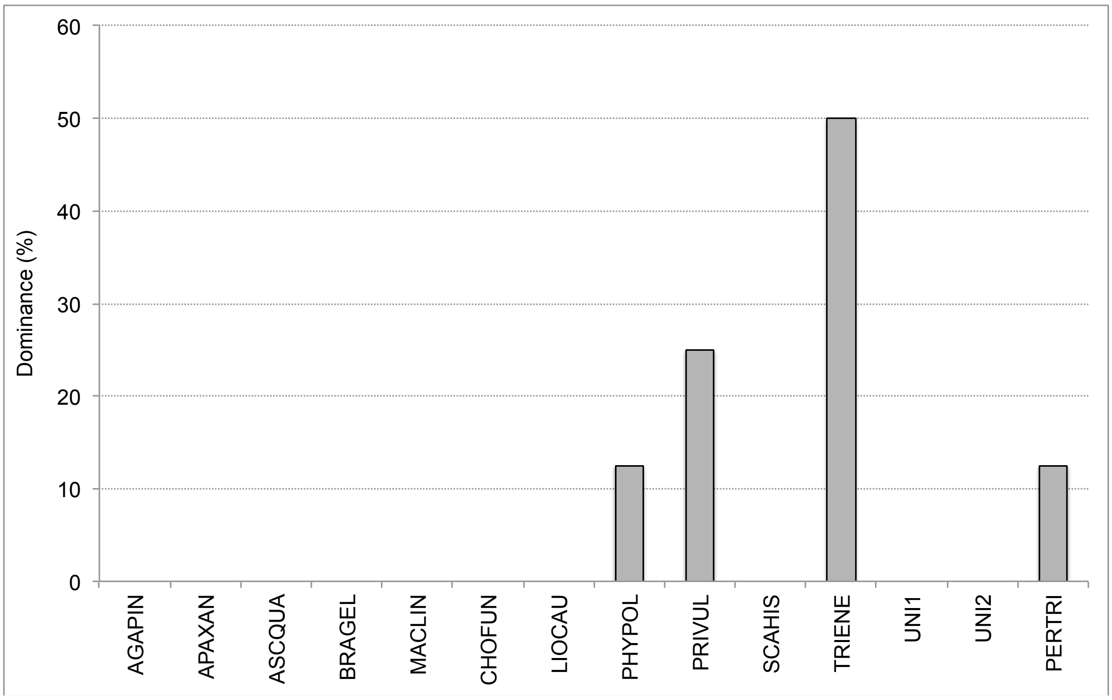


Fig. 3.22. Dominance (%) in Streuobst apple orchard located in Rommelshausen, 2014.

3.1.8. Fauna similarity among apple orchards in different regions distributed in Baden-Württemberg

The similarity between different apple orchards through the year distributed in Baden-Württemberg has been done by different measures such as Jaccard, Renkonnen and Wainstein indices (A 3.4 – A 3.7.). The measurements by Jaccard index brought the following results. In 2012, the locations in Plieningen and Hohenheim research center are similar to 0.4 and in 2013, the similarity dropped to 0.3 (Fig. 3.23. and 3.24.). In 2014, Rommelshausen and Ilsfeld showed maximum similarity (0.5) and Lake Constance showed the lowest similarity (0.2) (Fig. 3.25.). In 2015, the highest similarity (0,48) found between Neuhausen and Plieningen and no similarity among Emmendingen and Denzlingen in one side and the rest three orchards in Neuhausen, Plieningen and Scharnhausen (Fig. 3.26.).

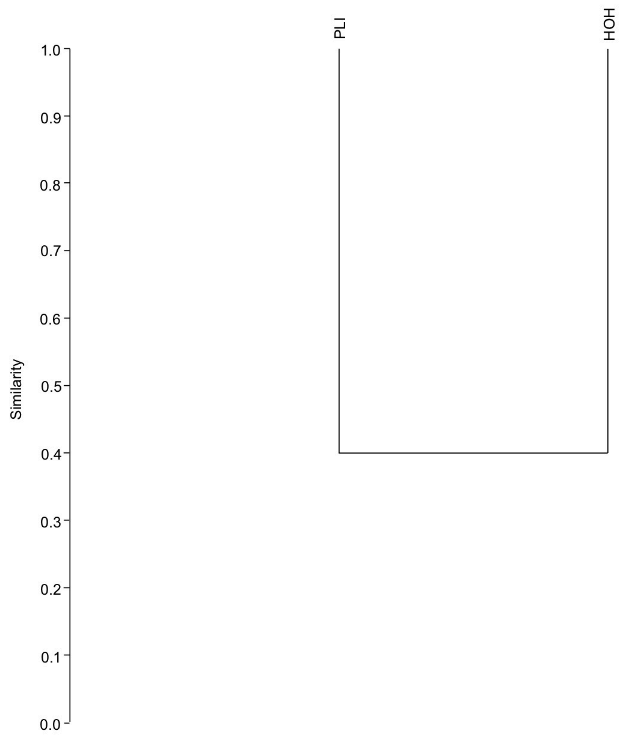


Fig. 3.23. Similarity based on Jaccard among apple orchards in 2012.

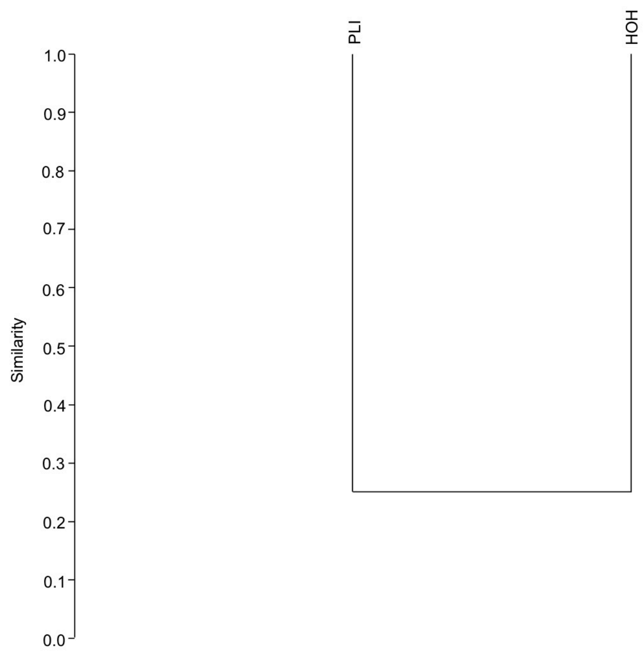


Fig. 3.24. Similarity based on Jaccard among apple orchards in 2013.

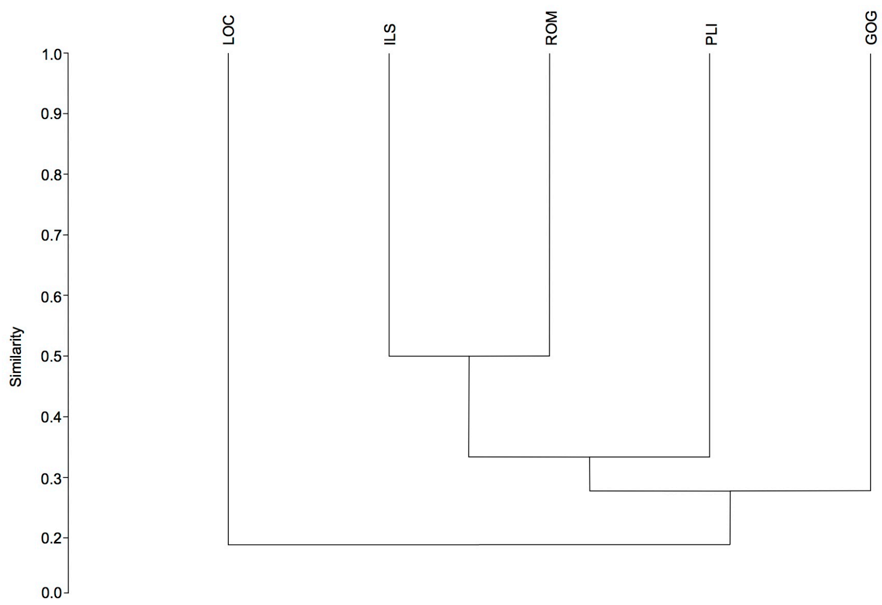


Fig. 3.25. Similarity based on Jaccard among apple orchards in 2014.

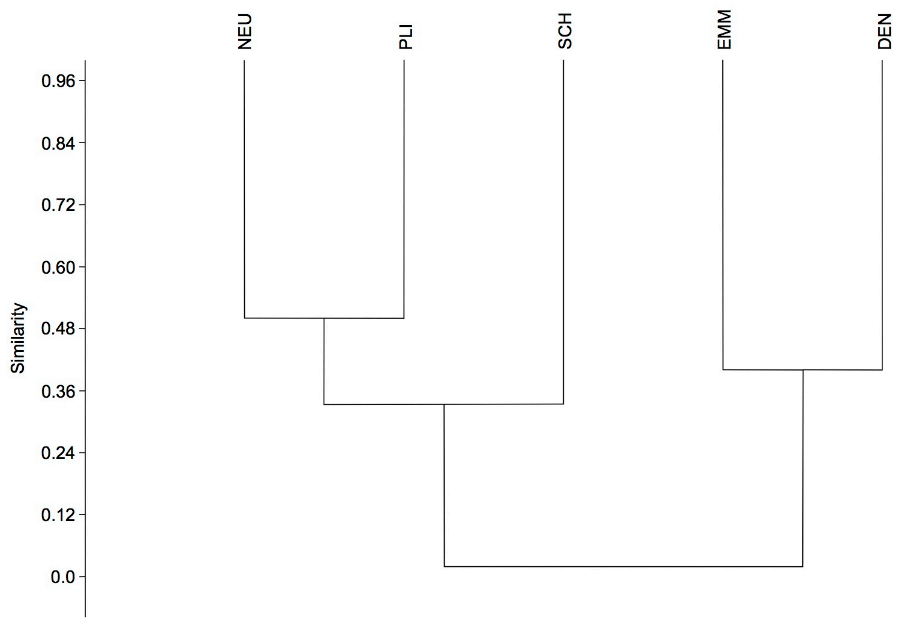


Fig. 3.26. Similarity based on Jaccard among apple orchards in 2015.

### 3.1.9. Species turnover

The four-year continuous sampling for larval parasitoids appeared as three courses of species turnover in Plieningen. The maximum species richness occurred on 2014 and the minimum species richness occurred on the first year 2012 (table 3.13.).

Two years (2012-2013 and 2013-2014) indicated no parasitoid species were lost but in the last course 2014-2015, five species including *L. caudatus*, *P. vulnerator*, *T. enecator*, Unidentified 1 and *P. tristis* lost from the community of larval guild. The entrance of new species as win species (*A. quadridentata*, *P. polyzonias* and *P. tristis*) to the region occurred on 2012-2013 (table 3.13.). The minimum turnover occurred on 2013-2014 and the maximum turnover occurred on 2014-2015 (table 3.14.).

Table 3.13. The species absent/ present through different years in Plieningen.

| | Orchard location | | | |
|---|---|---|---|---|
| | **Plieningen** | | | |
| | **Year** | | | |
| | **2012** | **2013** | **2014** | **2015** |
| **Larval parasitoid species** | | | | |
| *A. pini* | | | | |
| *A. xanthostigma* | **X** | **X** | **X** | **X** |
| *A. quadridentata* | | **X** | **X** | **X** |
| *B. gelechiae* | **X** | **X** | **X** | **X** |
| *M. linearis* | | | | |
| *C. funebris* | | | **X** | **X** |
| *L. caudatus* | **X** | **X** | **X** | |
| *P. polyzonias* | | **X** | **X** | **X** |
| *P. vulnerator* | **X** | **X** | **X** | |
| *S. hispae* | | | | |
| *T. enecator* | **X** | **X** | **X** | |
| Unidentified 1 (ichneumon) | | | **X** | |
| Unidentified 2 (ichneumon) | | | | **X** |
| *P. tristis* | | **X** | **X** | |
| **Species richness** | 5 | 8 | 10 | 6 |

Table 3.14. Rate of species turnover and species lost and win in the Plieningen orchard through 3 years.

| **Orchard location** | **Species turnover rate** | | | **Species lost** | | | **Species win** | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2012-2013 | 2013-2014 | 2014-2015 | 2012-2013 | 2013-2014 | 2014-2015 | 2012-2013 | 2013-2014 | 2014-2015 |
| Plieningen | 0.23 | 0.11 | 0.38 | 0 | 0 | 5 | 3 | 2 | 1 |

## 3.2. Socio-ecological studies in Iran

The survey to assess the *status quo* of general knowledge and IPM in apple production was conducted in 5 provinces of Iran. Different factors on social, infrastructure, IPM training and information which influence crop protection strategies and intensity were investigated.

### 3.2.1. Sociological information

*Ownership*

The ownership class distribution, family run farms, cooperatives, or companies, does not differ neither between provinces nor by region. However, in each region the family run farms were significantly outnumbering cooperatives and company run farms (Table 3.15.).

Table 3.15. The ownership distribution in provinces and regions.

| **Province / region** | **Family run farm** | **Cooperative** | **Company** | ***P* of $\chi^2$ *** |
|---|---|---|---|---|
| **E. Azerbaidjan** | **5** | **1** | **0** | **< 0.05** |
| Marand | 5 | 1 | 0 | |
| **Fars** | **10** | **1** | **0** | **< 0.001** |
| Abadeh | 0 | 1 | 0 | |
| Ardekan | 3 | 0 | 0 | |
| Hamayjan | 4 | 0 | 0 | |
| Sepidan | 3 | 0 | 0 | |
| **Isfahan** | **8** | **0** | **0** | **< 0.001** |
| Padenaolia | 7 | 0 | 0 | |
| Semirom | 1 | 0 | 0 | |
| **Tehran** | **9** | **0** | **1** | **< 0.001** |
| Damavand | 9 | 0 | 1 | |
| **W. Azerbayjan (total)** | **5** | **0** | **0** | **< 0.01** |
| Nazlu-chai | 3 | 0 | 0 | |
| Baranduz-chai | 2 | 0 | 0 | |
| **Total** | **37** | **2** | **1** | **< 0.001** |

* $\chi^2$ – test for categorical data (distribution-test).

*Age of the owner*

The mean age class in the province Isfahan, depicting a younger farmer on average, differed significantly from all other provinces assessed, where the farmers were older (Table 3.16.). No differences in average farmer's age were found within the provinces between different regions and villages.

Table 3.16. Age class (age classes given in A 2.1., means ± s.e.m.) of the farmers in selected Iranian provinces.

| Province | Owner age |
|---|---|
| E. Azerbaidjan | 7 ± 0.54 a<br>n = 5 |
| Fars | 6.44 ± 0.55 a<br>n = 9 |
| Isfahan | 3.75 ± 0.41 b<br>n = 8 |
| Tehran | 7.55 ± 0.44 a<br>n = 9 |
| W. Azerbayjan | 7 ± 0.63 a<br>n = 5 |
| F | 4.31 |
| d.f. | 9.21 |
| P | < 0.0001 |

(Oneway-ANOVA followed by LSD-test: α = 0.05).

*Education level of the owner*

The education level of the owner (classes) had significant interaction by different provinces not by regions and villages in Iran (Fig. 3.27.). The education level of the owners in different provinces and regions had a significant interaction (table 3.17.).

The education level of owner class distribution is distinguished into illiterate (1), primary school (2), secondary school (3), diploma (4), University relevant (5) and University irrelevant (6) (table A 3.8.)

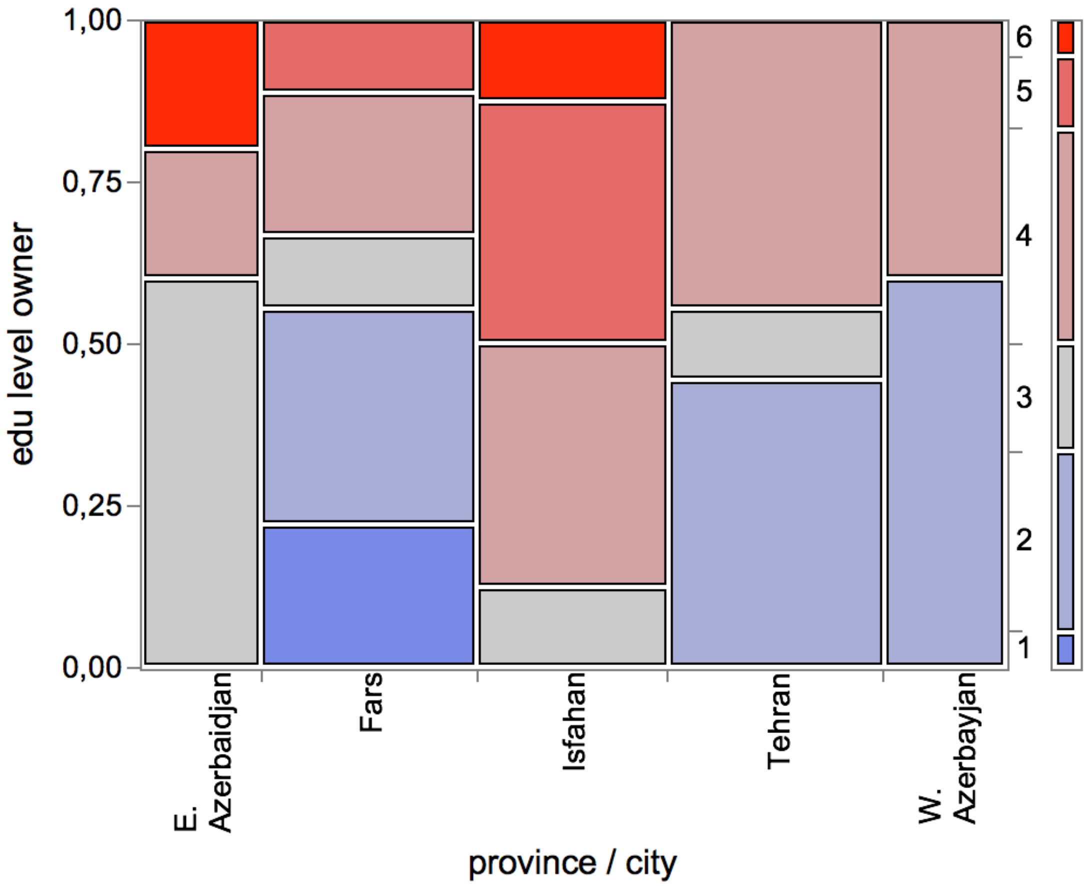


Fig. 3.27. Classes of the education level of the owner in different provinces in Iran. (Contingency by likelihood relationship (N = 36, d.f. = 20, loglike = 16.542, r = 0.2897, $\chi^2$ = 33.084, p = 0.0330)).

Table 3.17. Likelihood difference of education level of the owners in Iran.

| **Factor** | **Number of parameters** | **d.f.** | **P *** | **Lack of Fit P > $\chi^2$** |
|---|---|---|---|---|
| Province | 4 | 4 | 0.0155 | 0.1854 |
| Region | 9 | 9 | 0.0142 | 0.7013 |

(Ordinal log-model, following effect likelihood relationship; N = 36).

### 3.2.2. Infrastructure information

*The accessibility of road, market and expert to farmers in different provinces*

As distance to markets and crop protection experts may determine crop protection intensity, data on infrastructure were assessed. It was revealed by the analysis that there is difference between distances to nearest market by provinces but there are no differences by distance to the main road and nearest to the expert by provinces (Table 3.18.).

Table 3.18. Distances (km, means ± s.e.m.) of farms in selected Iranian provinces to the nearest main road, the nearest market, and the nearest expert.

| Province | Distance to | | |
|---|---|---|---|
| | **Nearest main road** | **Nearest market** | **Nearest expert** |
| Isfahan | 7.88 ± 2.01 a<br>n = 8 | 236.3 ± 24.56 a<br>n = 8 | 11.12 ± 1.96 a<br>n = 8 |
| Fars | 4.2 ± 2.87 ab<br>n = 10 | 83.0 ± 5.97 b<br>n = 10 | 20.8 ± 8.04 a<br>n = 10 |
| Tehran | 2.01 ± 0.48 b<br>n = 10 | 53.6 ± 9.91 bc<br>n = 10 | 15.7 ± 2.11 a<br>n = 10 |
| W. Azerbayjan | 4 ± 0.91 ab<br>n = 4 | 15.5 ± 5.49 cd<br>n = 4 | 16.5 ± 7.07 a<br>n = 4 |
| E. Azerbaidjan | 1.06 ± 0.21 b<br>n = 6 | 7.3 ± 2.39 d<br>n = 6 | 9.16 ± 2.22 a<br>n = 6 |
| F | 1.7431 | 44.1173 | 0.7728 |
| d.f. | 4.33 | 4.33 | 4.33 |
| *P* | 0.1641 | < 0.0001 | 0.5507 |

Means within a column followed by the same letter do not differ significantly (Oneway-ANOVA followed by LSD-test: α = 0.05).

*Frequency of visits of experts to apple producers and vice versa*

The frequency of visits of apple growers to crop protection expert had no significant relationship by age of the owner, distance to expert, and education level of the owner (table A 3.9.).

Crop protection expert visit had no significant relationship interaction with distance to expert and education level of the owner but there is a non-significant correlation was found with age of the owner, which could be taken as a trend (table 3.19.).

Table 3.19. Ordinal-logistic fit of expert visits to farmers by age, education level of the owner, and distance to expert.

| Source | Nr. of parameters | d.f. | Chi square | P |
|---|---|---|---|---|
| Age of the owner | 5 | 5 | 8.70 | 0.1214 |
| Distance to expert (classes) | 3 | 3 | 0.73 | 0.7269 |
| Education level of the owner | 5 | 5 | 0.27 | 0.2697 |

(Ordinal-logistic fit, Full model test, d.f. = 13, $Chi^2$ = 18.2800, P = 0.1472; $r^2$ = 0.1976, AICc = 144.253, observations = 35)

### 3.2.3. Diversity and distribution of apple cultivars

It was found that diversity of apple cultivars does differ by different provinces in Iran fig. 3.28. The frequency of apple cultivars in different provinces in Iran is shown in table A 3.10.

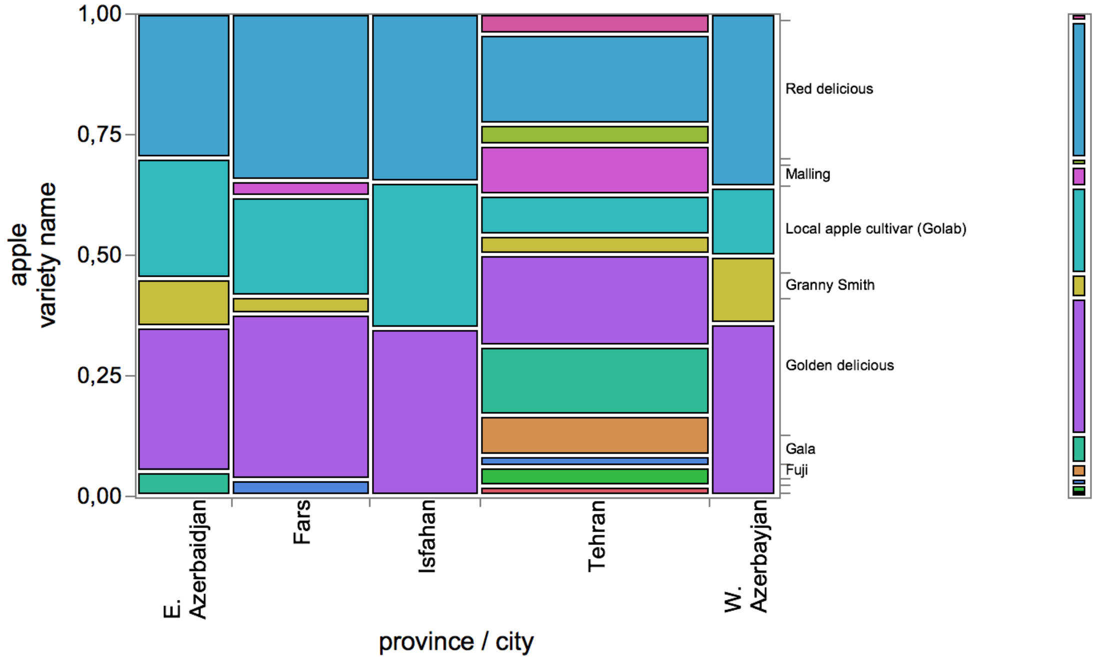


Fig. 3.28. Diversity of apple cultivars in different provinces in Iran (Contingency by likelihood relationship (N = 134, d.f. = 44, -LogLikelihood = 30.386, r = 0.120, $\chi^2$ = 60.772, p = 0.0475)).

It is also found that marketing (as first reason) is considered to grow a particular cultivar do differ with different provinces in Iran fig. 3.29. The most frequent reasons to grow a particular cultivar after marketing were according to neighbour experience and no purpose for cultivation.

The perception of farmers on resistance of cultivars against pest and diseases is versus the reality.

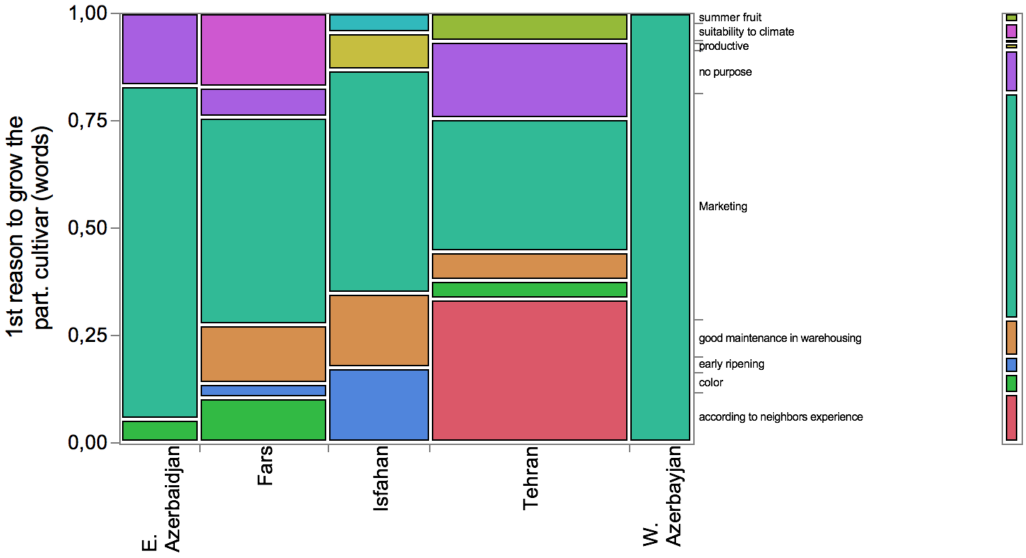


Fig. 3.29. Marketing as first reason to grow a cultivar by apple producers in different provinces. Contingency by likelihood relationship (N = 129, d.f. = 36, -LogLikelihood = 54.96, r = 0.26, $\chi^2$ = 109.933, p < 0.0001).

### 3.2.4. Prevailing damage intensities of pest, diseases and weeds in different provinces

Damage intensity had no significant interaction by disease but there is significant interaction with the pest's species and regions in Iran (table 3. 20.). The most damaging pests were *Cydia pomonella*, *Tetranychus urticae* Koch and *Aphis pomi* de Geer, respectively (fig. 3.30.). The damage intensity ranked from 1 to 3 from the least to highest damage occurred by the pest species.

Although the damage intensity occurred by disease agents has no significant interaction by species and regions, but damage intensity of weeds had interaction by the region (table 3. 21.).

Table 3.20. Damage intensity by pest species and regions.

| **Source** | **n** | **d.f.** | **Chi square** | **P** |
|---|---|---|---|---|
| Pest species | 11 | 11 | 26.12 | 0.0062 |
| Regions | 10 | 10 | 18.65 | 0.0448 |

Ordinal-logistic fit for damage intensity by pest species and region (Full model: d.f. = 21; $\chi^2$ = 46.8995, p = 0.0010; Lack of Fit: d.f. = 89, -LogLikelihood = 35.62983, $\chi^2$ = 71.25966, p = 0.9161).

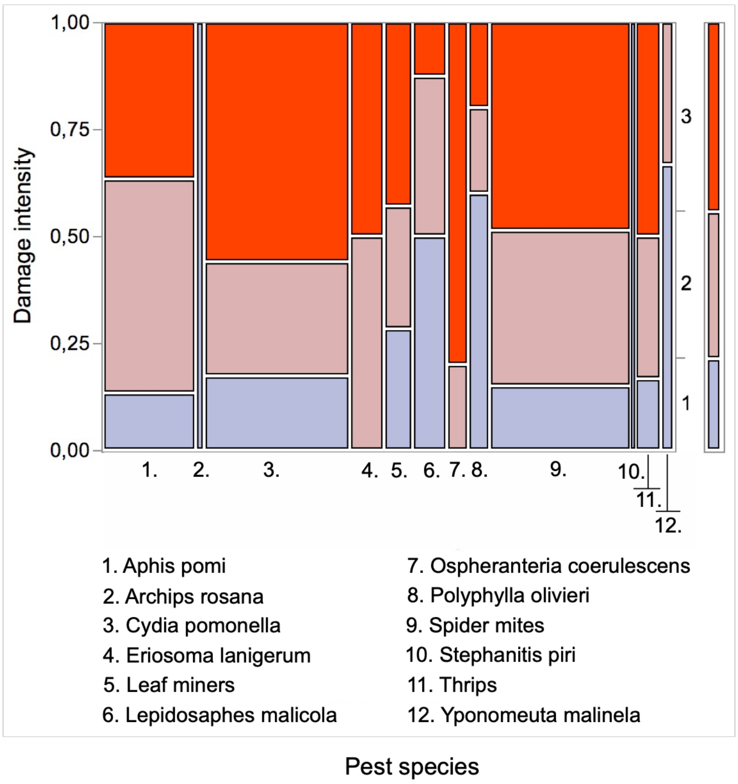


Fig 3.30. Damage intensity of different pests as a total of all 5 different provinces studied in Iran. Contingency analysis (N = 134, d.f. = 22, -LogLikelihood = 17.56, r = 0.1237, $\chi^2$ = 35.12, Likelihood-ratio p = 0.0376).

Table 3.21. Damage intensity by weed species and regions.

| Source | n | d.f. | Chi square | P |
|---|---|---|---|---|
| Weed species | 2 | 2 | 1.587 | 0.452 |
| Regions | 6 | 6 | 26.995 | 0.0001 |

Ordinal-logistic fit for damage intensity by weed species and region (Full model: d.f. = 8; $\chi^2$ = 30.91958, p < 0.0001; Lack of Fit: d.f. = 16, -LogLikelihood = 7.6877e-9, $\chi^2$ = 1.538e-8, p = 1.0000).

### 3.2.5. Pesticide classification, application, and practices

It was found that there was no interaction between total number of pesticide applications by maximum number of extension service contacts through different provinces and reliability to their advices and provinces (table A 3.11.). Pesticides application was varied through different provinces according to their native pests and diseases. The most pesticides used by the farmers were acetamiprid, confidor, decis, diazinon, dursban, fenvalerate, fozolon, malamite, and proteus. The most acaricides were abamectin, apollo, azocyclotin (propal), envidor, neoron, nissorun, omite, ortus, and propargite. They also used fungicides through the following fungicides such as benomyl, Bordeaux mixture, copper oxychloride, Trifloxystrobin, mancozeb, Kresoxim-methyl, penconazole and Thiophanat-methyl. The most prevalent herbicides used by fruit growers were limited only to Gramoxone, and glyphosate.

The frequency of pesticide application depended on the distance to experts, but it was found no interaction by education level of the crop protection expert, education level of the owner and provinces (Table 3.22.).

In the W. Azerbaijan, the 80% of the respondents declared that experts do not visit their farms. In Isfahan it drops nearly to 62,5% and rather lower in E. Azerbaijan with 50%. Compared to the rest of the provinces, Tehran enjoys a more coordinated management through visit meetings.

The orchards were categorized into three classes based on the number of pesticide application per year for each orchard. The intensity of pesticide application was low if the frequency of pesticide application was between 1-3, moderate between 4-5 and high if the frequency was more than 6 times per year against the pest species occurred in the apple orchards (table 3.24.).

Table 3.22. Frequency of pesticide application by distance to expert, education level of the plant protection expert, education level of the owner and provinces.

| **Source** | **n** | **d.f.** | **Chi square** | **P** |
|---|---|---|---|---|
| Distance to experts (classes) | 3 | 3 | 8.42 | 0.0380 |
| Education level of crop protection expert | 7 | 6 | 5.76 | 0.4503 |
| Education level of the owner | 6 | 5 | 9.86 | 0.0792 |
| Province | 4 | 4 | 8.31 | 0.0807 |

Ordinal-logistic fit for frequency of pesticide applications by distance to experts, education level of experts, education level of owners and provinces (Full model: d.f. = 20; $\chi^2$ = 26.80456, p = 0.1409; Lack of Fit: d.f. = 300, -LogLikelihood = 59.990608, $\chi^2$ = 119.9812, p = 1.0000).

*Knowledge on beneficial arthropods*

Nearly 70% of the respondents were unaware of natural enemies. The most common natural enemies known by the rest of fruit growers were as *Chrysopa carnea*, *Coccinella septempuctata*, and *Trichogramma sp.*

Farmers had almost some knowledge on healthy environment but they (70%) were hardly aware of the impact of insecticides on bee populations. In Tehran for instance, they were determined to refuse using bees because they believed bees are capable to propagate “fire blight” disease agent in the orchard.

### 3.2.7. Apple cultivation area

Apple area cultivation had a significant interaction by provinces (Fig. 3.31.). The distribution of apple area cultivation in different provinces can be found in table A 3.12.

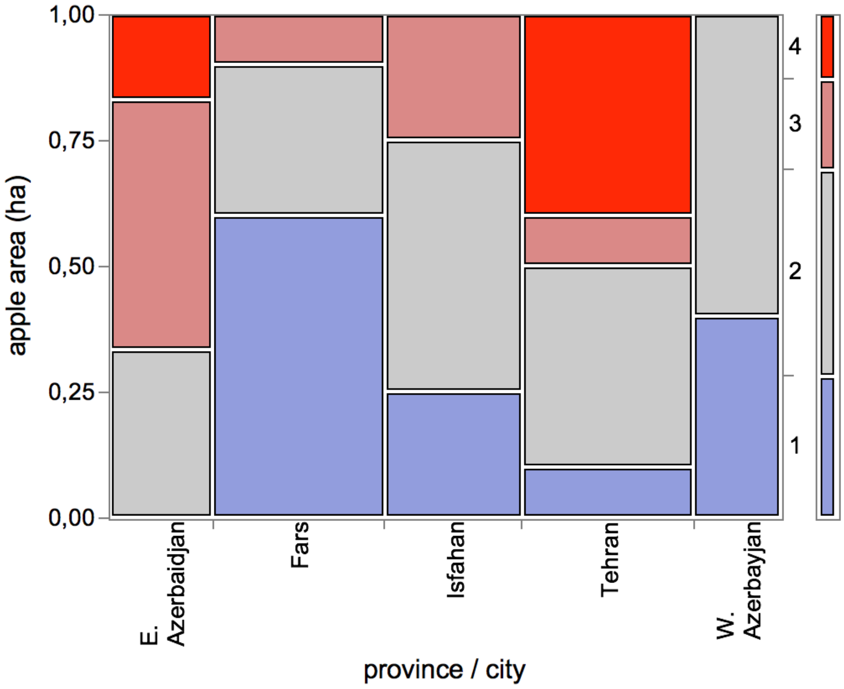


Fig 3.31. Apple area cultivation by provinces. Contingency analysis (N = 39, d.f. = 12, log like = 11.8058, r = 0.2339, $\chi^2$ = 23.612, p = 0.0230).

Table 3.24. Distribution and frequency of damage intensity separated by pest species and management intensity of plant protection in different provinces in Iran.

| Orchard Nr. | Province | Key dominant pest | Order; Family | Damage intensity | Nr. insecticide app. per year | Insecticide appl. intensity |
|---|---|---|---|---|---|---|
| 1 | E. Azerbaidjan | Aphids | Hemiptera; Aphididae | 3 | 13 | 3 |
| | | *Archips sp.* | Lepidoptera; Tortricidae | 3 | | |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| | | *Eriosoma lanigerum* | Hemiptera; Aphidadae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 2 | E. Azerbaidjan | *Tetranychus urticae* | Acari; Tetranychidae | 3 | 3 | 2 |
| 3 | E. Azerbaidjan | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 3 | 2 |
| 4 | E. Azerbaidjan | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 7 | 3 |
| 5 | E. Azerbaidjan | *Aphis pomi* | Hemiptera; Aphididae | 2 | 3 | 1 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 2 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 2 | | |
| 6 | E. Azerbaidjan | *Cydia pomonella* | Lepidoptera; Tortricidae | 2 | 2 | 1 |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 2 | | |
| 7 | Fars | *Anaphotrips sp.* | Thysanoptera; Thripidae | 3 | 6 | 3 |
| | | *Aphis pomi* | Hemiptera; Aphididae | 3 | | |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| | | *Osphranteria coerulescens* | Coleoptera; Cerambycidae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |

Table 3.24. (continued)

| Orchard Nr. | Province | Key dominant pest | Order; Family | Damage intensity | Nr. insecticide app. per year | Insecticide appl. intensity |
|---|---|---|---|---|---|---|
| 8 | Fars | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 6 | 3 |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 9 | Fars | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 4 | 2 |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 10 | Fars | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 2 | 1 |
| | | *Eriosoma lanigerum* | Hemiptera; Aphidadae | 3 | | |
| 11 | Fars | *Eriosoma lanigerum* | Hemiptera; Aphidadae | 3 | 3 | 2 |
| | | *Lepidosaphes malicola* | Hemiptera; Diaspididae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 12 | Fars | *Aphis pomi* | Hemiptera; Aphididae | 1 | 2 | 1 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 1 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 1 | | |
| 13 | Fars | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 4 | 2 |
| | | *Osphranteria coerulescens* | Coleoptera; Cerambycidae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 14 | Fars | *Anaphotrips sp.* | Thysanoptera; Thripidae | 3 | 6 | 3 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| | | *Osphranteria coerulescens* | Coleoptera; Cerambycidae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |

Table 3.24. (continued)

| Orchard Nr. | Province | Key dominant pest | Order; Family | Damage intensity | Nr. insecticide app. per year | Insecticide appl. intensity |
|---|---|---|---|---|---|---|
| 15 | Fars | *Aphis pomi* | Hemiptera; Aphididae | 3 | 5 | 2 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| | | *Osphranteria coerulescens* | Coleoptera; Cerambycidae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 16 | Fars | *Tetranychus urticae* | Acari; Tetranychidae | 2 | 3 | 1 |
| 17 | Isfahan | *Eriosoma lanigerum* | Hemiptera; Aphidadae | 2 | 2 | 1 |
| 18 | Isfahan | *Aphis pomi* | Hemiptera; Aphididae | 2 | 3 | 2 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 2 | | |
| 19 | Isfahan | *Eriosoma lanigerum* | Hemiptera; Aphidadae | 3 | 3 | 1 |
| 20 | Isfahan | *Tetranychus urticae* | Acari; Tetranychidae | 2 | 3 | 1 |
| 21 | Isfahan | *Cydia pomonella* | Lepidoptera; Tortricidae | 2 | 2 | 1 |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 2 | | |
| 22 | Isfahan | *Aphis pomi* | Hemiptera; Aphididae | 3 | 3 | 1 |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 23 | Isfahan | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 3 | 1 |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 24 | Isfahan | *Aphis pomi* | Hemiptera; Aphididae | 2 | 3 | 1 |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 2 | | |
| 25 | Tehran | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 7 | 3 |

Table 3.24. (continued)

| Orchard Nr. | Province | Key dominant pest | Order; Family | Damage intensity | Nr. insecticide app. per year | Insecticide appl. intensity |
|---|---|---|---|---|---|---|
| 26 | Tehran | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 4 | 1 |
| 27 | Tehran | *Tetranychus urticae* | Acari; Tetranychidae | 2 | 6 | 2 |
| 28 | Tehran | *Archips sp.* | Lepidoptera; Tortricidae | 3 | 2 | 1 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| 29 | Tehran | *Anaphotrips sp.* | Thysanoptera; Thripidae | 3 | 3 | 2 |
| 30 | Tehran | *Tetranychus urticae* | Acari; Tetranychidae | 3 | 3 | 1 |
| 31 | Tehran | *Aphis pomi* | Hemiptera; Aphididae | 2 | 3 | 2 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 2 | | |
| 32 | Tehran | *Aphis pomi* | Hemiptera; Aphididae | 3 | 1 | 1 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 33 | Tehran | *Archips sp.* | Lepidoptera; Tortricidae | 1 | 3 | 2 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 1 | | |
| | | *Stephanitis pyri* | Hemiptera; Tingidae | 1 | | |
| | | | | | | |
| | Tehran | *Tetranychus urticae* | Acari; Tetranychidae | 1 | | |
| | | *Yponomeuta malinella* | Lepidoptera; Yponomeutidae | 1 | | |
| 34 | Tehran | *Cydia pomonella* | Lepidoptera; Tortricidae | 2 | 3 | 1 |
| | | *Eriosoma lanigerum* | Hemiptera; Aphidadae | 2 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 2 | | |

Table 3.24. (continued)

| Orchard Nr. | Province | Key dominant pest | Order; Family | Damage intensity | Nr. insecticide app. per year | Insecticide appl. intensity |
|---|---|---|---|---|---|---|
| 35 | W. Azerbayjan | *Aphis pomi* | Hemiptera; Aphididae | 3 | 4 | 1 |
| | | *Archips sp.* | Lepidoptera; Tortricidae | 3 | | |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 36 | W. Azerbayjan | *Aphis pomi* | Hemiptera; Aphididae | 2 | 3 | 1 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 2 | | |
| | | *Polyphylla olivieri* | Coleoptera; Scarabidae | 2 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 2 | | |
| 37 | W. Azerbayjan | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | 4 | 2 |
| 38 | W. Azerbayjan | *Aphis pomi* | Hemiptera; Aphididae | 3 | 3 | 1 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |
| 39 | W. Azerbayjan | *Aphis pomi* | Hemiptera; Aphididae | 3 | 5 | 2 |
| | | *Cydia pomonella* | Lepidoptera; Tortricidae | 3 | | |
| | | *Polyphylla olivieri* | Coleoptera; Scarabidae | 3 | | |
| | | *Tetranychus urticae* | Acari; Tetranychidae | 3 | | |

# 4. Discussion

4.1. General discussion

The endeavours in this research focused on two main parts: (i) ecology of apple orchards focussing on the effect of management intensity on food webs, and (ii) socio-ecology of Iranian apple production.

The larval parasitoids of tortricid apple pests were addressed to describe the effects of management intensity on biodiversity and ecological functionality of this important group of antagonists in South-western Germany. The second part deals with the *status quo* of plant protection intensity in Iranian fruit orchards focusing on biodiversity issues for future diversity improvement, antagonist conservation and optimization of biocontrol. The scopes to study on holistic approaches were beyond the limits of the thesis.

Intensively managed orchards are characterized by few, but dominant species, most of them belonging to arthropod pests. In addition to natural mortality factors, insecticide application affects the herbivore community and, indirectly, the antagonist complex (Clancy and McAlister 1958, Massee 1958, MacPhee and MacLellan 1971, Hislop and Prokopy 1979, Madsen and Madsen 1982, Liss et al. 1986, Strickler et al. 1987).

In arthropod communities both, pests and their antagonist's complexes, are considered as entities, in which their constituent species produce patterns in abundance and distribution (Gaston and Lawton 1988, Holt et al. 1997, Lawton et al. 1998). Dominance structure, evenness, and community composition can be used to assess the anthropogenic impact on natural enemy populations but they are not capable to recognize the changes in functional structure, species interaction, and ecosystem functioning and essential services in functioning of ecosystem. Food webs, another aspect of community structure, can be predicted from models using very simple and general descriptions of species interactions. They are effective to analyse species interactions in complex communities and to provide functional components of biodiversity (Laska and Wootton 1998, McCann 2007, Tylianakis et al. 2007).

One of the important priorities to manage an agro-ecosystem in a sustainable manner is to conserve and encourage the biological diversity. Studies to investigate the richness and abundance of antagonist's species in different agricultural management systems have been grown (Jahnke et al. 2007). To describe a community structure and compare natural conditions to what changes in human-induced ecosystems, the biodiversity indices are the major approach to be studied. These indices are subjected to identify the changes and conserve the biodiversity (Oliver and Beatle 1993). The perennial crops, in particular, are the best examples to describe such human-manipulated changes in agro-ecosystem in order to develop and improve management capacities, which implement the sustainability in local diversity. Conserving natural resources through ecological based management strengthens country life by increasing sustainability, which eventually ensures food security (Altieri 2002).

The members of hymenopteran parasitoid communities encompass a large number of species, which interact with the host arthropod species and regulate their populations. Therefore, their reaction to the environmental disturbance can be considered as biological health indicator of a particular habitat (Lewis and Whitfield 1999, Forehand et al. 2006). For short-term the abundance of natural antagonists would be more influential than species richness because the reduction of pest population is the result of increase of beneficial individuals rather than species richness alone (Wratten and van Emden 1995). However, for a long-term approach, the higher diversity of natural antagonists to control the pest species is important but the selection of diversity indicators is more important (Duelli and Obrist 2003). The assessment and comparison of diversity indicators over the time in different locations may provide basis knowledge on how to preserve species (Purvis and Hector 2000). Many studies have shown the role of natural enemies on the dynamics of host / prey and their parasitoids / predators (Morris 1959, Murdoch et al. 1989, Gould et al. 1990, Turchin 1990, Berryman 1996). In some cases, with no doubt, natural enemies were capable to reduce the host population density (Utida 1957, Bellows and Hassell 1988, Hassell and May 1988, Bonsall and Hassell 1997, Shimida 1999).

The present study aimed to better understand the diversity, structure and composition of larval parasitoids of tortricids and gelechiids and providing information that may be used for management and control of malicious apple orchards arthropods.

## 4.2. Discussion of methods

In spite of reports on effectiveness of some parasitoids to monitor pest populations as biological control agents (Hessel 2013, Perado et al. 2015), this efficiency may fluctuate through different species and antagonist's communities. The impact of beneficial arthropods as larval parasitoids to regulate the herbivore communities in apple orchards, which is manifested in their rate of parasitism, is not impressive to suppress the pest's species. The efficiency of larval parasitoids according to their biological parameters was not possible to gain while all species in given communities were impossible to rear in lab conditions, so the accurate estimation on the possible parasitism rate would not be accessible. The complex interaction of herbivore species is not limited to antagonistic arthropods and it stretched to other top-down agents such as single cell creatures (bacteria, fungi, and bacteria), birds, and predators influencing the density of host populations in the region of Baden-Württemberg, so rough estimate of collected larvae by corrugated cardboards did not depict a real herbivore population, and consequently it affects the parasitism rate.

The installation of corrugated cardboards was based on the existence of apple fruits on the trees, which increases the expectation of *C. pomonella* species. These cardboards are representative of indirect infestation by herbivore pest's population and showing the activity of larval pest populations, not necessarily parasitized ones. As the hibernating larvae would not remain in the fruit and would depart to the ground (most dominantly near to the apple trunk Broufas et al. 2002, Stará and Kocourek 2004), even larvae in the fruit were not expected as matured enough to be parasitized by the larval antagonists, as we experienced the higher parasitism rate on *C. pomonella* occurred on last larval instar in Streuobst management, when larvae are migrating for overwintering in middle of October. The balanced infested fruits were impossible to gain, while other agents would affect the fruit and kill the larvae such as decaying substrate or fungi infestations. The intensity of orchard management showed indirect effect on diversity and abundance of target beneficial species, through elimination of host species in intensive management. It makes the balanced number of sampling impossible, while integrated management also followed the same conditions by other different pesticide of natural origins such as Kupferhydroxid, copper, sulphur, Azadirachtin (Neem), *Cydia pomonella* granulovirus (CpGV), *Adoxophyes orana* granulovirus (AoGV), soap, and pyrethrum (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit 2016).

The estimate of infestation and parasitism rate per apple tree for all tortricids and their relevant antagonist's species through direct observation was not easy, while the time of collection would be deterministic for identification of apple cultivars. As leaf tortricids are active in the early of growing season, the fruit apples were not ripe enough to be identified. Marking the trees for following sampling years would also be affected by the availability and accompanying of apple growers for a continuous sampling. A more flexible sampling location (Hohenheim research centre) was deleted in sampling plan because the trees suffered rust disease and led to the eradication of all examined apple trees in the following years. The time of collection of *C. pomonella* and its larval-parasitoid guild was incongruent with the existence of ripe fruit apples, enabled us to identify apple cultivars and to link parasitism rate per apple tree.

As discussed earlier, the methods we used did not elucidate the effect of hyper-parasitoids, larval competition, and apparent competition of parasitoids, but connectance was considered, being the most important index to describe food web complexity (Loreau 1988, Snyder et al. 2006, Tilman 1977a, b). The underlying ecological parameters constituting larval-parasitoid diversity in perennial crops, such as plant and floral diversity, density, habitat complexity, phenology, and alternative host population size would decrease or increase parasitism rate. These features should be assessed separately to know which factor to which degree can influence parasitism rate.

## 4.3. Diversity and abundance of larval-parasitoids

The parasitoid species obtained in the current study is congruent with previous results reported from different ecosystems (Kot 2007, Kot and Jaśkiewicz 2007a, Kot and Jaśkiewicz 2007b). Predominantly the firm impact of larval parasitoids among other arthropod antagonists and birds are assumed to keep the summer fruit tortrix, *A. orana*, and other members of tortricids below the injury level (Blommers and Helsen 1989). However, other limiting factors such as fungi, viruses, and bacteria should also be taken into account. More than the latter limiting factors, the parasitization rate is directly correlated with crop protection intensity in orchards against pest species (Athanassov et al. 1998).

## 4.4. Spatial and temporal appearance of antagonists' species, alternative host range and influence of landscape fragmentation.

As the Shannon-Wiener index would be affected by species richness and their abundance, it depicts in this study how beneficial populations and their community structures would be affected by plant protection management and intensity of pesticide application. The factors influencing the larval-parasitoid communities are not restricted on the local patches (considered as apple orchards in the current study) and exclusively management type and/or intensity matters. The distribution and abundances of different beneficial species as prospective biological agents depends on other different factors. The existence of suitable habitats and their connection can increase the dispersion of natural antagonists in larger spatial scale. The vicinity of foraging patches and roosting ones would increase the population of natural antagonists, compared to isolated patches (landscape complementation). However, the proportion of alternative suitable habitats in a landscape, which is permanent and undisturbed, also increase the dynamics of natural enemies. Woodlands, shrubs, field margin strips, and adjacent crop fields may maintain the alternative prey for beneficial wasps. These natural habitats may increase the efficacy of natural enemies when the density of pests as hosts decrease (Marrec et al. 2017). For instance, Rosenberg (1934) reported 16 alternative host species for *T. enecator*, which may serve as potential source to enhance the parasitoid activity.

The area "Goldener Grund" encompasses aged apple trees, which are surrounded by urban structures to the north and west, and a vast cultivated area to the south. The connectivity to western woodland is restricted due to annual fields and human activities, which make this part more isolated and its ecological connectivity decreased. The disappearance of a prevalent and predominant species *T. enecator* can explain such isolation. The dominance of *A. xanthostigma* may define the adjacent of orchard to cultivated areas and availability of agricultural herbivores.

Habitats accommodating flowering wild weeds can provide nectar and pollen, which enhance the potency of arthropod antagonists (Jervis et al. 1993, Wäckers 2001) and rate of parasitism (Berndt et al. 2006) and even semi-natural habitats (Streuobst) can contribute to biodiversity (Duelli and Obrist 2003). The dispersion of larval-parasitoids is not facilitated exclusively by the abundance of flowering plants or diverse vegetation, but well-connected patches. While the nearby conventional orchard management interrupt the habitats by intensive mulching and affect the permeability of species from one patch to another, fragmented habitats with a lower diversity are the result. Due to such deficiencies in ecological infrastructure, the beneficial communities seem to be uneven and less diversified in Streuobst management. Lake Constance, Rommelshausen, and Emmendingen can be described as habitats, which are affected by intensity crop protection management, in spite of vicinity to dense woodland and jungles nearby.

Parasitization varies among landscape structures. The phenological characteristics of herbivores and their parasitoids differ in their spatio-temporal distributions, which may lead to phenological asynchrony. Parasitization rates would increase in highly connected habitats compared to isolated ones (Cronin 2003, Murakami et al. 2008, Farzan et al. 2017, Morgan et al. 2017). The larval-parasitoid assemblages represent the variation in biodiversity measures in different patches (orchards) in Baden-Württemberg. The frequency of abundant parasitoids indicates their preference in woodland habitat covered by aged trees with well-developed canopies found in Plieningen, which represented the highest Shannon-Wiener diversity index. This area encompasses scattered shrubs and grassy coverage, which makes a favourable location for larval parasitoids activity. Human inhabitants occupy the eastern part of the region, but there is a corridor in western side, which connects to an open deciduous forest with low human input. Such conditions increase the complexity of habitat, led to enhance the diversity and abundance of parasitoids. The abundance oscillations in *A. xanthostigma*, *M. lineatus*, *S. hispae*, and UNI2 (ichneumonid) species probably have different reasons. The availability of alternative hosts may decrease their dynamics on tortricids and gelechiids. The lowest diversity index is related to Denzlingen by intensive management, which contains no beneficial species.

The diversity indices (Shannon-Wiener and Simpson) are measures of biodiversity, which take the species richness and their relative abundance into account. A higher index represents a higher diversity and evenness in a natural community. The amount would fluctuate between 0 and 1, and 1 would represent the highest evenness in a community. The most even communities belong to Streuobst management, and as we consider through different management systems, the less, lesser, and least even communities would appear in organic, integrated, and intensive managements, respectively. The diversity indices are not only affected by the management type but also intensity of pesticide application in different regions. Different Streuobst management in different regions may exert significant interaction with the diversity index. The unbalanced and uncompleted sampling would be the reason for such differences. The installation of corrugated cardboards is essential to obtain host larvae, *C. pomonella*, which enjoys a higher range of larval-parasitoids compared to the rest of herbivore tortricid and gelechiids affecting diversity indices in Scharnhausen, Neuhausen, and the last year of sampling in Plieningen.

Maybe the current statistic comparison may serve to initiate a broader study with a higher participation of commercial apple producers, a wider range of species and a higher number of commercial orchards without pesticide use and “clean” trees.

### 4.5. Taxonomic association

The present study showed some evidences of hyper-parasitoid dynamics, which sporadically appeared in just one sampling season. Three different morphologically species (Hym: Pteromalidae) were found on *B. gelechiae*. Contrary to be considered as hyper-parasitic species, in the current study *P. tristis* was found as primary parasitoid of *C. pomonella* (Mills 2005). Molecular studies (DNA barcoding) seem to be applied on the accuracy of further identifications.

### 4.6. Apparent competition

Different herbivore species sharing the same parasitoid species are directly affected in their population density depending on the host preference by the parasitoid. Neglecting any other mortality factor and assuming similar preference for both host species, the effect of parasitization on population dynamics is identical. Assuming dissimilar preference for the hosts, the less preferred species may profit from higher parasitization rate of the preferred species and increase in population density the next generation(s). However, when the preferred host species is lacking, the less preferred species serves as major host and may decrease in population density while the other host species recovers, resulting in anti-cyclic population dynamics of both host species. This extreme example may serve to explain a balanced host-parasitoid complex, enhancing the resilience and stability in a habitat. Although, the fourth trophic level as hyper-parasitoids may mediate parasitoid communities and consequently affect the apparent competition (van Nouhuys and Hanski 2000, van Veen et al. 2001, 2017). In spite of its importance, examining of such indirect interactions in the real natural conditions is rare and difficult, because these studies require (very) long observation periods not realized yet. The natural abiotic factors affecting population dynamics of both, pest and parasitoid communities, are difficult to describe and to be put into ecosystem models (Morris et al. 2001).

The host-parasitoid interactions in Plieningen (2013) indicated the rate of parasitism of *L. caudatus* on *C. pomonella* (in spite of its highest abundance to the rest of hosts) is less than on *R. leucatella*. It is also evident that the rate of parasitism of *A. xanthostigma* occurred on the least abundant shared host so it is obvious that a simple connection between apparent competition and parasitization rate seem unlikely. However the rare cases studied on apparent competition, Frost et al. (2016) showed that apparent competition is strong enough to predict future parasitism rate and herbivore abundances, which help us to promote habitat management and landscape planning.

The parasitism rate of *A. xanthostigma* fluctuates per orchard and season between the shared hosts. It is still in doubt to say “host preference” occurred. Three sampling seasons show *C. pomonella* as major host compared to *H. nubiferana* and *A. xylostena*, but in one season the parasitism rate outweighs to *H. nubiferana* and the last sampling season shows nearly equal parasitization rate between three shared larval hosts. The underlying mechanisms for such behaviour need more studies as mentioned above in the simple example. Furthermore, there may be some other alternative unidentified hosts for *A. xanthostigma*, which have indirect effects on the parasitism rate and responsible for parasitoid behaviour.

Most current studies on apparent competition have been focused on non-spatial approach. In natural communities, victim species (herbivores) are assumed to try to escape predation or parasitism to an enemy free space to minimize their exposure (vulnerable developmental stage) to natural enemies’ attack by at least three factors such as size, morphology, and position, which a victim species may occupy in a habitat. Furthermore, herbivores may displace a character, which is a consequence of selection pressure imposed by natural enemies to occupy empty niche free from parasitization / predation and arise a sympatric speciation.

The alternative hosts may indirectly reduce the other host’s abundance (apparent competition) by a shared parasitoid species or even lead to exclude co-existing alternative host herbivores (less preferred) from community composition by a shared polyphagous parasitoid species, which arise dynamic monophagy (Holt and Lawton 1993). However, the abundant or preferred alternative host may lead to apparent mutualism, which reduces the impact of natural enemies, in favour of herbivores to escape parasitism.

The capability of distribution in different parasitoid species differs and the knowledge on that is limited (van Nouhuys and Hanski 2000).

### 4.7. Food web connectance

The stability of an ecosystem is affected by connectivity of the species involved. The debate still exists on the role of connectivity on enhancing or decreasing the stability in an ecosystem functioning (Pimm 1979, McCann et al. 2005). Regardless to ethical perspective to conserve the species, it should not be neglected that they play key and vital role on food supply (Millennium Ecosystem Assessment 2005, Díaz et al. 2006, Dobson et al. 2006, Tallis et al. 2008). However, species preservation serves higher biodiversity and the interaction networks among species may promote the stability. In communities comprising herbivores and parasitoids, the number of links describes specialisation or generalism – the higher the number of links the higher the level of generalism. The less specialized parasitoids may interact on a wider host range and it provides a buffer against herbivore oscillations, which drive beneficial to alternative hosts.

Anthropogenic activities can create adverse effects on the interaction networks in a mutualistic interaction even when the species richness is unaffected, which postpone the co-occurrence of species in a habitat (McCann 2007, Tylianakis et al. 2007, Aizen et al. 2008). In an antagonistic interaction, such human induced management may affect the reproduction, growth, migration patterns, and local abundance. The life history traits of herbivores and parasitoids are also affected through match and mismatch in their phenology leading to the asynchronous appearance and network connectivity (Durant et al. 2007).

Similar connectance values between Streuobst and organic management found in Denzlingen (2014) can be explained by close vicinity of the orchards to intensive managed orchard. The neighbouring intensive management also affected the overall species richness and values of connectivity of the rest of the orchards due to probable pesticide drift during the control period. The most Streuobst orchards are characterized by higher connectance values, and the integrated managed orchards ranked in minimum.

Thus, it may be concluded that the stable communities vary with the number of species and relative abundance, which increase the level of complexity, and connectance may directly affect stability (Fowler 2009). Food web structure in different orchards by different managements showed variation in family and even more in subfamily levels with more or less similar guild of parasitoids, where the plant protection intensification varied. Although the network size of food webs under study are all limited to larval-parasitoids and they do not reveal a real picture of network and its size (e.g. the role of hyper-parasitoids, predator species and other single cell parasites), Higher abundance of larval-parasitoids in Streuobst systems reflects promising ecologically methods in contrast, intensive managements where commercial (conventional) orchards contained no tolerance for natural antagonists.

## 4.8. Species turnover

The changes in parasitic community composition depend on colonization, extinction, and sampling effects. The most abundant and common species such as *T. enecator* enjoy the broadest host range and can be considered as generalist. This species is unlikely to extinct locally, which explains the effect of sampling efforts not implemented between 2015-2016 in spatial species turnover (Plieningen). The same reason would explain on the existence of *L. caudatus*, *P. vulnerator*, and *P. tristis*, which share the same hosts larvae.

## 4.9. Probable reasons for low parasitism rates by larval-parasitoids

The adult parasitoids need energy resources such as nectar, pollen, or honeydew to improve their demographic parameters and physical performance such as searching efficiency (Berndt et al. 2004, Benelli et al. 2016, Charles et al. 2016). If supplementary food resources are scarce or lacking, these parameters would be negatively affected. The human intervention can minimize the food (weed suppression or single cropping system) and destroy refuges and shelters used by natural enemies (Wardle et al. 1999, Kienzle et al. 1998a, b). The ground cover vegetation brings diversified niches in favour of phytophagous species and consequently to parasitoid communities (Altieri and Schmidt 1985).

The efficiency of foraging among parasitoids depends on several factors. If searching activity is affected by external inputs (i.e. chemical insecticides), this behaviour may be interrupted in a period of time. Therefore, the synchronization between host herbivore generation and its natural enemies may be mismatched, and in case that the natural enemy cannot find the non-parasitized alternative host, she leaves the area (or perishes due to a long time searching) and indirectly parasitism rate decreases. The number of searching parasitoid female in one generation depends on the proportion of parasitized hosts in the previous generation, so such interruptions affect the population dynamics as well.

Furthermore, under natural conditions, parasitoids are sensitive on searching activity by the rest of antagonistic species. The searching adult female parasitoids may encounter already parasitized hosts or chemical tracks left by the previous parasitoid individuals, which repels newly arrived individuals and enforce them to depart to another area (Waage 1979, Mills 1991). However, this should result in a better dispersion and higher parasitization rates.

In order to escape parasitism, host herbivores hide themselves temporally and spatially. They confine themselves in part of a habitat, which is free from parasitoids (Bailey et al. 1962, Murdoch and Oaten 1989, Holt and Hassell 1993, Krivan 1998), or they do not expose their vulnerable developmental stage to parasitoids in the overlapping time of adult female parasitoid activity (Münster-Swendsen and Nachman 1978, Münster-Swendsen 1980, Godfray et al. 1994).

## 4.10. Density dependence

The stability of interacting arthropod species (host herbivore and larval-parasitoid species) within a natural community is manifested by density dependence. Natural antagonists would be considered as reliable regulators when they are capable to impose density dependent mortality. To estimate the host-parasitoid population dynamics, the parasitism rate represents the force of antagonist's species to induce mortality on host herbivores, which can have a depressive effect led to population regulation (Hanskey 1992, Hassell 2000, Haak 2002).

The studies on arthropods communities did not exclusively indicate the density dependent pattern, but also it has detected that the top-down effect can be density independent (Hanskey 1992, Lessells 1985, Stilling 1987, Norowi et al. 2000). Natural reasons may influence the host-parasitoid dynamics such as effectiveness of individual parasitoid (potency, sex ratio, foraging capacity), competition between parasitoids, hyper-parasitoids, predators, and spatial and temporal distribution of herbivore populations (Hunter and Price 1998, Lessells 1985, Loch and Zalucki 1998, Visser et al. 1999, Strong 1989, Driesssen et al. 1995). The scale of sampling and the number of replicates would also affect the quantification of host-parasitoid interactions, which makes it more complicated to investigate what is ecologically happening in reality (Hails and Crawley 1992, 4.2. discussion of methods), furthermore when attack rates by larval-parasitoids are less than 10% and the abundance of hosts are not high enough, a calculation of density dependence might be biased and is not recommended.

However, some species of larval-parasitoids showed positive relationship to herbivore host density (table A 4.1.), but sequential parasitization by different larval-parasitoids through a larval-parasitoid complex might obscure the virtual relationship.

The heterogeneity of neighboring patches (e.g. intact natural locations) and ecological infrastructures (corridors) would increase a higher probability of density dependence through the orchards by the same management (Streuobst). The differences in attack rates indicate how neighboring intact (natural) patches contribute to increase the frequency distribution of number of hosts (or alternatives) (table 3.1.) and consequently to a higher density dependence. The temporal fluctuations occurred annually on host populations would also tend density independence, but the complex ecological factors still suffer such clarifications. Thus, adjacent vegetation may provide primary or alternative hosts and may indirectly affect the response of parasitoids to host abundances. Any estimation of species richness of agricultural land should include the vegetation and structure diversity.

## 4.11. Increasing the survival chance of beneficial arthropods

Rational application of pesticides can help to conserve and promote natural enemies. To comply a suppressive outcome on pest species and reduce the risk of natural enemy mortality, one should identify the targeted arthropod community. This identification should not be limited to taxonomic features but also to its functional attributes in a given agro-ecosystem. Different developmental stages in host herbivores may be occupied by different parasitoids, which constitutes a guild complex through egg, larvae, and pupae. Such complexes define the functional attributes of a parasitic community, which influence host density. However the parasitoid efficacy as limiting factor may not represent a suppressing strength on arthropod herbivores, they may constitute a complex, which reacts as a buffer specifically for generalist's species. The knowledge on such guilds depicts a practical scheme to conserve dominant parasitoid species in a given habitat.

Temporal and spatial dynamics of natural enemies in accordance to ecological infrastructure may influence the frequency of pesticide application. The serious pest species, which remain above the economic threshold, are deserved to control. Key pest phenology and non-overlapping generations with parasitic species may determine the accurate time of pesticide application. The time, which pest exposes to pesticides, shows the least susceptible developmental stage to parasitoids during a growing season.

A key pest may have several life cycles through one growing season. Some generations may be free from parasitoid overlapping generations in a given habitat. This may arise due to the interaction strength of parasitic species to alternative herbivore hosts, which may exist in adjacent habitat. The probable evolutionary or ecologically phenomenon or the influence of apparent competition and or host preference, which is responsible to such overlapping versus non-overlapping generations, would be conserved and promoted by a well-connected metrics of patches. Such corridors may facilitate the distribution of one parasitoid generation from last growing season of parasitized hosts in one habitat to another and bring them back to the same habitat. Although, the hypothesis "source and sink" supposes when the species leave the source habitats, they never come back to their originating habitat.

One of the major features of IPM, monitoring of pests and following economic injury levels determining pesticide application, at best done as precision application, are capable to reduce adverse pesticide side effects (Mann et al. 1991, Fadamiro 2004).

The synthetic pesticides often act as broad-spectrum toxicants killing a wide range of non-target arthropod taxa. Biorational pesticides, either synthetic or of natural origin, are more selective and protecting natural enemies. Biocontrol using microorganisms such as fungi, bacteria, and viruses can attack to pest species specifically, which bear less harmful consequences for non-target parasitoid species.

The inaccurate dosage of pesticide would lead the mortality of natural enemies. The sub-lethal dosages (residues, contaminated water droplet, nectar, and pollen) may affect the parasitoid behaviour (Tappert et al. 2017, Wang et al. 2017). The restriction of pesticide application where the pest species are active and technics such as spry pattern, nozzle sizes would increase conserving zones. Host plants in borders of fields and pheromones to absorb herbivore species and systematic pesticides would also decrease pesticide-contaminated areas (Johnson and Tabashnik 1999, flint and Gouveia 2001, Rea et al. 2002, Youn and Jung 2008).

## 4.12. *Status quo* of plant protection in Iran

Sustainability in agriculture is an interdisciplinary approach, which is rather vague and difficult to be interpreted and it is still a matter of debate (Rigby and Caceres 2000, Velten et al. 2015). Sustainable orchard production can be considered as a sign of sustainable development and it is achieved via integrated pest management (IPM) to protect the plants against pest species on the purpose of healthy crop production, food security, and green environment by reducing broad-spectrum synthetic pesticide application, which is devastating to natural communities. It is also expected to be a long-time process with no degradation to natural resources.

The identification of the ecological basis solely cannot progress the sustainability equation, but different aspects of social, economic, and political managements would be fit to achieve a sustainable agriculture. To understand how well ecological approaches in plant protection are incongruent with the infrastructure and IPM conditions in Iran, we designed a questionnaire to find out which primitive obstacles exist. The present study is a preliminary step to depict the *status quo* of plant protection to provide a better picture on future managing orchard management and decision-makings to reduce the unsustainable practices in Iran. To investigate a suitable system vs. conventional management in Iran, we assess the ecological components (in Germany, Baden-Württemberg) to depict how well the ecological approaches may affect biodiversity indices of natural enemies, which is considered as sustainable approaches. The infrastructural and social parameters were evaluated by 39 respondents to see the circumstances of plant protection in Iran, which may affect the farmer mentality to launch IPM approaches.

### *Land tenure and biodiversity*

As the dominant ownership of fruit orchards run by the smallholder farmers (94.87%), the cooperative IPM approach would be rather difficult. The land tenure system has created highly fragmented patches, which may propagate the unsustainable practices by different individual farming activities. The cultural practices of one farmer, who does not care to cut and collect the infested branches of scale insects (i.e. *Lepidosaphes malicola* Borchsenius), would infect the neighbouring orchards. The range of pesticides and frequent applications of one farmer can affect the biodiversity of beneficial arthropod of adjacent orchards.

*Damage intensities by different agents*

In comparison with disease and weed species, the pests' species can cause damage. The damage intensity of both pests and weed species has significant interaction by the regions (table 3. 20. and 3. 21.). The reasons would fluctuate in different regions, but different aspects can cause different effects on the status of damage intensity such as climate change, average annual precipitation, water supply, and agricultural managements. In recent years, the decline of annual precipitation and water supply has caused an environmental shift in different parts of Iran, which consequently has brought potential invasive species, although the agricultural management and expert teams would also contribute to exacerbate the damage intensity region by region. The unavailability of climate data on each location (orchards) of a region, leads to a vague wide range of precipitation records and potential studies would not be possible to link the environmental shift to damage intensity occurrence. The agricultural management needs an improved and modified updated climate system, which allows having accurate assessments on such links.

*Private sector and fostering sustainable practices*

Although the education level of the farmers does not affect the frequency of pesticide applications, but the distance to expert matters. One side of the coin is the responsibility of experts to support the area given to them, furthermore farmers still have dispute on the knowledge of experts to be unreliable to accept. These reasons caused the farmer visit frequency from experts remain steady as expert visit. Some of the experts believe that the scarcity of budget for their transportation (oil expenses, transport services) is a constraint to follow regular extension visits.

*Accessibility to infrastructure*

The accessibility to road, market, and expert (logistic infrastructures) promotes sustainability of production. It also motivates the fruit growers to produce ecologically and receive premiums. In Isfahan province (Padenaolia region), the accessibility of apple growers to the nearest market is poor and they are not able to offer their products. In spite of being a well-known apple production, apple growers suffer market access compared to the rest of regions in Iran. Having highly qualified apple products, they export to other countries. The apple export seems to be done exclusively by a company, which is able to impose the trend in Iranian apple market. The monopoly and the loss of market liberalization would restrict the financial outcome, which make the farmers hopeless and lose their motivation on ecologically apple production approach.

*Apple cultivars*

The frequency and distribution of apple cultivar is brought in table (A 3.5.). Three dominant cultivars are Golden Delicious, Red Delicious, and Golab (local cultivar) in all provinces. The most diversified varieties were exclusively found in Tehran by five cultivars such as Braeburn, Delbar Estivale, Fuji, Miracle, and Star King. It indicates that the capital enjoys a support for cultivar varieties while the rest in spite of having a good climate to grow apple has been deprived of such support. The dominant reason to choose a particular cultivar is marketing in all provinces. This indicates that the farmers are not well informed how to choose the cultivar through ecological parameters such as resistance to pest and diseases, productivity in a suitable climate. It is only marketing oriented attitude to produce more with no attention to susceptibility of cultivar against pest's species. In Tehran the reason to choose also can be influenced by the neighbours, which indicates the poor and or unreliability of expert offers.

*Pests*

Among the damaging factors, pest species were devastating agents in different orchards in different regions. It seems that the outbreak and resurgence of *T. urticae* is the indicator of excessive usage of synthetic pesticide application, which caused this secondary species become a prevalent and even key pest in most of the orchards. In different regions, weeds can be considered as damaging factor.

*Apple area cultivation*

We found that small-scale orchards are prevalent and distributed in all provinces. It seems one of the problems according to the pest management is related to higher increase of small-scale farming. The number of pesticide applications increases when a neighbour does not follow the regulatory practices in cooperation with the rest of counterparts and their orchard turns to be a refugee for the pests and becomes source for re-emergence of next pest outbreak. In such systems, the farmers suffer a strong social network and cooperative interaction to control and monitor the pest problems.

*Intensification of pesticide application*

Although fruit orchard protection requires different pesticides and fungicides, but it is questionable how many times pesticide application during a growing season is reasonable and rational. The high number of pesticide application within an orchard can cause anthropogenic perturbation into natural communities (i.e. parasitoids) and decrease their efficiencies. The frequency of pesticide usage has been brought in table 3.19.

Approximately 56% of fruit growers in Iran use pesticides as both preventive and curative purposes. The combination of both strategies seems rather rational for plant protection. There is a difference among provinces, for example in W. Azerbaijan, 80% farmers use pesticides only as prophylactic tool. Using solely one strategy can lead to an excessive usage of pesticide and increase the number of pesticide application, so it affects the natural enemy communities.

The farmers with high intensification of pesticide application indicates that their knowledge on the phenology of pest species and its host plants is poor, as 66,66 % of farmers declared that they do not follow this strategy.

## Conclusions and recommendations

The unsustainable farming practices such as pesticide application make the conventional orchards unstable (Drinkwater 1995). Studying different management strategies verified that human disturbance could alter the community structure. Such changes are visible through patterns of relative abundance and biodiversity measures (Lewis and Whitfield, 1999). In the present study, different richness and diversity indices showed significant changes in composition of parasitoid complexes associated with leafrollers and codling moth in different orchard management systems in Baden-Württemberg. As hypothesized, the orchards with minimal insecticide inputs (Streuobst) showed higher diversity and richness indicating a home to support a more diversified environment. Conventional systems (intensive management) represented a low diversity and in some sampling years no results in species existence, which cannot sustain parasitic individuals. We found that more preserved orchards save a potential healthy environment to protect the diversity and keep the density of larval parasitoids to their host herbivores. The ecological approach should be evaluated according to changes in diversity and the species abundances. This contributes to enhance environmental health, which is in parallel on sustainable practices (Magurran 1988).

What we have gained is a survey through a questionnaire asking from 39 fruit growers from different provinces in Iran. They mostly cultivate apple and mixed fruit orchards. This observation occurred in the July 2016. These data are representing the *statues quo* of plant protection and further investigations are needed for better understanding of the IPM issues. Some sporadic studies have been done by Rasouliazar (2011) and Mahmoudi (2014) on IPM adoption and social obstacles in organic agriculture but it seems economical and political issues still are in dire need of clarification. These factors are the basis to build a sustainable agriculture, which should be interconnected well to be reliable and resist in a lone-term approach. In order to improve the biodiversity of natural enemies and decrease the amount of pesticides, the following recommendations would be taken into account:

- The application of pesticide should be rational by using selective pesticides, which cause human perturbation to be harmless for the beneficial communities and may facilitate pest suppression by natural agents.
- The accessibility of illegal pesticides, which are useless to control pest, should be banned and legal authorities should guarantee and supervise the chemical trades.
- The government should support scientific-based companies in order to research on biocontrol agents. Providing scientific infrastructure to produce microbial and selective pesticides, and rearing natural enemies (e.g. predator and parasitoids) in insectarium for mass production increase the fitness in accordance to IPM programs.
- Training IPM would not be enough and practical program should be exerted and supported. IPM certificate should be awarded to farmers in order to motivate them to produce products, which receive rather less or zero chemical pesticide.

- There should be a plan designed to enhance the landscape structure complexity in order to support the natural enemies.
- Intellectual application of phenological scheme in a multi-trophic community (host plant, host herbivore, and natural enemies) should be fit on different features of beneficial arthropods (idiobiont, koinobiont, time of activity). In combination with the biological features, the landscape structure also can be designed to provide a buffering environment to enhance the functional diversity host plants through maintaining alternative host herbivores and even providing shelter for parasitoid hibernation. These complexities would support the flowering plants, which serve as alternative food source for adult parasiotids (lengthening the longevity and strengthening the productivity, can consequently enhance parasitism and top-down effect)
- A network to send SMS or mobile application to forecast the emergence of pest and disease, which gives advice and information to all farmers in the area simultaneously.
- The potential cultivars should be investigated in research sections such as universities or private sectors. The propagation and conferring the suitable and diversified cultivars should be taken into account to enhance the biodiversity of trees and make them more resistant against prevalent pest and diseases.
- To achieve a long-term stable agricultural production, there would be a harmony among different factors such as policy-making, IPM strategies, social, and economical aspects. The ecological scales to support beneficial arthropods should be extended to natural communities in a spatial scale of eco-regions. A need for well-trained specialists to support farmers choosing ecologically based approaches may promote the parallel tactics to monitor pest populations and biological control. The development of scouting and phenological models of multi-trophic community (host plant, host herbivore, and biological control agents) should be designed by application of applied sciences to implement the success of sustainability in IPM strategies. The efforts should be in direction of knowing different parameters of life history of beneficial. A wide variety of factors, such as sex determination, sex allocation (under influence of endosymbiont, female mother age), body size, egg limitation (pro-ovigeny vs. syn-ovigeny), starvation of adult female, host stage structure, which increase the competency of arthropod communities. Landscape structure and buffering effects would enhance conserving species through the time, which increase the chance of biological pest control.
- The understanding and adoption of the ecological responsibility on the sustainable practices among farming communities toward conserving biodiversity should be promoted.

## Abstract

Although a consensus through the concept of sustainable agricultural production and its indicators to assess its functionality varies, it is expected to be long-term and reliable. The sustainability would change temporarily and spatially. It is influenced by political, social and economical issues, which reveals its interdisciplinary essence in concert with farming strategies and practices to produce human food. The management of plant protection is capable to impose unsustainability into farming system. The frequency and intensity of unsustainable practices would result into devastating effects on diversity and abundance of beneficial arthropods. The communities of natural enemy may promote sustainable management, but the anthropogenic interventions such as broad-spectrum pesticide applications would distort the essence of self-monitoring of natural invertebrates as regulators. The conventional agricultural management makes the habitats to be simplified through food webs and ecological complexities, which lead to species loss (extinction or emigration) and consequently to species interactions (connectance). The ecologically based management such as integrated pest management (IPM) would focus to maintain species and increase diversity in natural communities, which contributes to sustainable approach as alternative versus conventional agriculture. The negative effects of chemical pesticides would dramatically decline the ecosystem process and affect the energy flow among different trophic levels, which is manifested as functional rates in local or regional scale of ecosystem. The human-manipulated areas create negative consequences on the ecosystem functionality through vanishing the key natural resources (i.e. shelter, food provision, and alternative host prey), which affect maintaining natural enemy communities. The complementarity effects of antagonist communities can lead a synergetic impact on pest control, when biodiversity is conserved through vegetation, rational bio-pesticide application, and ecological infrastructure, the functional traits (richness and evenness) among interacting species will be improved. Furthermore, the intensified agriculture would arise pest outbreaks or convert a secondary and unimportant pest into a serious one. The antagonistic communities may represent as bio-indicators. The presence or absence of higher trophic levels and their complexes would reflect biotic or abiotic changes in the environment, which would eventually be expressed as parasitism or consumption rate.

The scope of current research is limited to indicators of sustainability through pest management and does not comply a holistic approach on ecological, political, social, and economical managements. The preliminary results focus on the *status quo* of plant protection in Iran and biodiversity indices in Germany used to compare the different farm systems to show how the management can affect the community components and their interactions. The environmental and anthropogenic impacts on biodiversity of beneficial arthropods in different orchard management conducted in Germany, where the accessibility of abandoned apple orchards is more prevalent than Iran.

To evaluate the impact of conventional intensive management vs. ecologically based sustainable practices on invertebrate beneficial community, a comparative study was conducted to assess

food web pattern of larval-parasitoid communities, biodiversity indices, and parasitism rate in response to apple orchard by four different managements. Field samplings were occurred during 2011-2015 in Baden-Württemberg, Germany. The orchard managements were distinguished based on the frequency and intensity of pesticide applications into the farming system. The categories of orchard management were managed (organic and integrated), and Streuobst (semi-abandoned orchard), which were situated in Denzlingen, Emmendingen, Goldener Grund, Hohenheim research center, Ilsfeld, Lake Constance, Neuhausen, Plieningen, Rommelshausen, and Scharnhausen. The sampling was conducted by installation of corrugated cardboard and random observation to collect larval caterpillars (Tortricidae and Gelechiidae). The collected samples were transferred to lab to rear adult parasitoids and further studies on taxonomic affiliation. Out of 7,923 healthy host larvae collected, totally 324 parasitoid individuals from three subfamilies of Braconidae, Ichneumonidae, and Perilampidae were found. Four parasitoid species were found positive host-density dependent, the rest of the parasitoid species showed no density-dependency or were found in too small numbers. The highest richness, abundance, and evenness of larval-parasitoids were found in Streuobst orchards (i.g. Plieningen), which received no to minimal pesticide inputs. The interaction diversity of food webs (connectance) in Streuobst showed the highest number of trophic links in response to other orchard managements where the commercial (conventional) orchards harbor no to the least biodiversity indices of beneficial arthropods. Percentage similarity also assessed to depict the similarity of larval-parasitoid community structures in different managements. It was revealed the orchards with the same management contain similar parasitoid compositions.

To describe and analyze the information on apple growing management, circumstances of plant protection, pest status, and major obstacles to initialize sustainable production in Iran, a questionnaire was designed to survey 39 apple growers from East-Azerbaijan, Fars, Isfahan, Tehran, and W. Azerbaijan in July 2014. It was found that management of the orchards mostly is under the supervision of the apple growers. Farmers in Isfahan suffer a road infrastructure to have an access to the nearest market to sell their product indicating an economic monopoly. The distance to experts affects the intensity of pesticide application by farmers. The conventional agriculture is prevailing in all provinces and access to bio-pesticides highly limited to Tehran. Totally 29 pesticides were used against different fruit pests in Iran. The most damage intensities occurred by pests in province scale and weeds in regional scale. The outbreak of secondary pest Tetranychus urticae as key one indicates human perturbations in Iran's farming system. Tehran province enjoyed diverse apple cultivars contrary to other provinces, which are poor in diversification. The predominant outlook to choose a cultivar among apple growers was marketing.

**Zusammenfassung**

Der Begriff „nachhaltige landwirtschaftliche Produktion“ zielt auf zukunftsfähige ressourcenschonende Wirtschaftsweise ab, die in der Gesellschaft zunehmend Akzeptanz findet. Wie sich Nachhaltigkeit gestaltet ist regional und zeitlich variabel und wird von politischen, sozialen und ökonomischen Themen beeinflusst. Die Landwirtschaft ist unter anderem durch die Nutzung von Pflanzenschutz und chemischen Pflanzenschutzmitteln in der Lage, dauerhaft stabile Erträge zu sichern. Der intensive Einsatz von nicht-nachhaltigen Praktiken kann jedoch zu verheerenden Auswirkungen auf die Vielfalt und die Fülle von nützlichen Arthropoden führen. Eine nachhaltige Bewirtschaftung kann dagegen natürliche Gegenspieler von Schaderregern fördern, aber die vom Gesetzgeber verursachten Interventionen, wie das breit angelegte Spektrum von Pestiziden, können die Selbstkontrolle von natürlichen Gegenspielern als Regulatoren verzerren bzw. negativ beeinträchtigen. Die konventionelle Landwirtschaft kann Lebensräume, ökologische Strukturen, Nahrungsnetze und funktionelle Biodiversität zerstören. Die Folgen sind Emigration, der Verlust von Arten und vereinfachte interspezifische Wechselwirkungen.

Die Umsetzung von Maßnahmen zur nachhaltigen landwirtschaftlichen Produktion bedürfen geeigneter Parameter zur Abschätzung des *status quo* und des Erfolgs der durchgeführten Maßnahmen. Diese Parameter sind nicht immer vorhanden und müssen erarbeitet werden.

Diese Arbeit hatte das Ziel, anhand von Erhebungen des Artenaufkommens der Wickler (Tortricidae) und ihrer Larvalparasitoide in Apfelanlagen mit unterschiedlicher Bewirtschaftungsintensität und der davon abgeleiteten ökologischen Indices geeignete Parameter zu erarbeiten. Diese sollten die Auswirkung der Benutzungsintensität auf die funktionelle Biodiversität wiederspiegeln und geeignet sein, die Umsetzung von Nachhaltigkeitsmaßnahmen zu bewerten.

Um den Einfluss konventioneller bzw. ökologischer Bewirtschaftung auf Wirbellosengesellschaften zu untersuchen, wurde eine Vergleichsstudie durchgeführt, die Nahrungsnetze der Larvalparasitoide, Biodiversitäts-Indizes und Parasitierungsraten in Apfelanlagen mit vier verschiedenen Bewirtschaftungsweisen erfasst. Die Probenahmen erfolgten 2011-2015 in Baden-Württemberg.

Nach Intensität der Pflanzenschutzmittelanwendung wurden die Anlagen in die Kategorien Bewirtschaftet (ökologische und integrierte Bewirtschaftung) und Streuobst eingeteilt. Sie lagen in Denzlingen, Emmendingen, Goldener Grund, Versuchsstation Hohenheim, Ilsfeld, Neuhausen, Plieningen, Rommelshausen, Scharnhausen und am Bodensee. Die Probenahmen bestanden im Sammeln der Raupen (Tortricidae und Gelechiidae) mit Fallen aus Wellpappe und durch Zufallsfunde.

Im Labor wurden die daraus schlüpfenden adulten Parasitoide taxonomisch bestimmt. In 7923 Larven fanden sich 324 Individuen von Parasitoiden aus drei Unterfamilien der Braconidae, Ichneumonidae und Perilampidae. Die größte Vielfalt, Häufigkeit und gleichmäßige Verteilung an

Larvalparasitoiden fand sich auf Streuobstwiesen (z.B. in Plieningen), die keine oder nur minimale Pestizid Anwendungen erhielten. Die Interaktionsmuster der Nahrungsnetze (Verknüpfungsgrad) im Streuobst wiesen die meisten trophischen Links auf, verglichen mit anders bewirtschafteten Anlagen unter denen die kommerziellen (konventionellen) die geringste Biodiversität an Nutzarthropoden beherbergten. Ihre prozentualen Anteile wurden ebenfalls erhoben, um die Ähnlichkeit der Larvalparasitoid-Gesellschaften unter verschiedenen Bewirtschaftungen darzustellen. Es stellte sich heraus, dass Anlagen mit gleicher Bewirtschaftung ähnliche Parasitoiden-Gesellschaften aufweisen. Vier Parasitoiden-Arten erwiesen sich als positiv dichteabhängig von ihren Wirtsarten, während die anderen Arten entweder nicht dichteabhängig reagierten oder in zu geringen Zahlen auftraten, um eine Korrelation zu berechnen.

Um Informationen über Bewirtschaftung im Apfelanbau, Bedingungen für den Pflanzenschutz, Schädlingsbefall und Haupthindernisse für die Förderung nachhaltiger Anbaumethoden im Iran zu erhalten und zu analysieren wurden im Juli 2014 mittels Fragebogen 39 Apfelanbauer aus Ost-Aserbeidschan, Fars, Isfahan, Teheran und West-Aserbeidschan befragt. Die Bewirtschaftung der Anlagen stand meist unter Aufsicht der Apfelanbauer. Bauern aus Isfahan litten unter mangelhaftem Ausbau der Straßen was ihnen den Zugang zu Märkten für den Absatz ihrer Produkte erschwerte.

Die räumliche Entfernung zu Fachleuten beeinflusste die Intensität des Pflanzenschutzmittel Einsatzes durch die Bauern. Konventioneller Anbau überwog in allen Provinzen; Zugang zu Biologischen Pflanzenschutzmitteln war weitgehend auf Teheran beschränkt. Insgesamt 29 Pestizide wurden gegen Obstschädlinge im Iran eingesetzt. Im regionalen Maßstab wurden die höchsten Schäden durch Unkräuter verursacht, auf der Ebene der Provinzen durch Schädlinge. Ausbrüche des Sekundär Schädlings *Tetranychus urticae* waren ein Anzeichen für menschliche Störfaktoren in der Landwirtschaft des Iran. Die Provinz Teheran verfügte über mehrere Apfelsorten während andere Provinzen eine geringe Vielfalt aufwiesen. Unter den Apfelproduzenten erfolgte die Sortenauswahl vorrangig nach Kriterien der Vermarktbarkeit.

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# Appendix

A 2.1. Questionnaire

**General information**

Region:

Village:

Distance to the main road (km):

Distance to the nearest market (km):

Distance to the nearest agricultural extension office (km):

**Farmer information**

Orchard owner: family ☐ cooperative ☐ company ☐

Age of the owner (if not company), cross one:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Below 20 | 21-25 | 26-30 | 31-35 | 36-40 | 41-45 | 46-50 | Over 50 |

Sex: (1) female, (2) male ☐

Number of family members:

Level of education of the owner, cross one:

| | | | | |
|---|---|---|---|---|
| Illiterate | Primary level | Secondary level | Diploma | University (agric./hortic.) |

Age of the orchard manager, cross one:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Below 20 | 21-25 | 26-30 | 31-35 | 36-40 | 41-45 | 46-50 | > 50 |

Sex: (1) female, (2) male ☐

Level of education of the farm manager, cross one:

| | | | | |
|---|---|---|---|---|
| Illiterate | Primary level | Secondary level | Diploma | University (agric./hortic.) |

Who is responsible for crop protection? Family member ☐ cooperative ☐ company ☐ employee ☐

Age of the person responsible for crop protection, cross one:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Below 20 | 21-25 | 26-30 | 31-35 | 36-40 | 41-45 | 46-50 | > 50 |

Sex: (1) female, (2) male ☐

Level of education of the person responsible for crop protection, cross one:

| | | | | |
|---|---|---|---|---|
| Illiterate | Primary level | Secondary level | Diploma | University (agric./hortic.) |

**Land use**

Area (hectares) under all crops

Area (hectares) under apple:

| | | | |
|---|---|---|---|
| <1 hectare | 1-3 hectare | 3-6 hectare | >6 hectare |

How long have you grown apples?

How do you plant the fruit trees?

| | |
|---|---|
| In rows | Traditional |

How many apple trees are there per hectare? _________ Ha

Which apple cultivars (varieties) do you have in the orchard?

Please specify the 5 top apple cultivars in your orchards and why do you grow these cultivars?

| **Cultivar** | **Comment(s)** |
|---|---|
| | |
| | |

Do you use resistant plant varieties? Yes ☐ No ☐

If yes

Resistant varieties (Resistant to pests or diseases)

| **Cultivar** | **Disease** | **Status** | **Cultivar** | **Pest** | **Status** |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

status: S = susceptible, I = intermediate, R = resistant

In which time intervals (years) do you replant the orchards?

Do you mix the apple trees with other fruit trees? Yes ☐ No ☐

If yes; which kind of fruit trees do you mix with apple trees?

Which major constraints have you encountered in apple production and how do you solve the problem? (Also mention when there is no solution)

| **Production constraints** | **Solution** |
|---|---|
| | |

**Soil**

How often do you monitor the nitrogen-content in the soil for improvement of production?

Do you use fertilizers? Yes ☐ No ☐

If yes,

| Fertilizer | How many times per year? | How much nitrogen per hectare? |
|---|---|---|
| Mineral | | |
| Organic | | |

Irrigation system (if any)

| | |
|---|---|
| Modern (sprinkler, droplet) | Traditional |

How much water do you use per hectare (if you know or as a rough estimate)?

Do you use domestic animals in the orchard? Yes ☐ No ☐

If yes,

| | | |
|---|---|---|
| Sheep | Cattle | Chicken |

**Biodiversity**

Which major pests/ diseases/ weed you have experienced in apple growing for the last three years?
What was the damage level resulting from the above pests and diseases?
Which practice did you use in the management of the above-mentioned pests and diseases in apple?

| **Disease/ pest/ weed** | **Damage level (1 = slight; 2 = moderate; 3 = severe)** | **Management practices** |
|---|---|---|
| | | |

Pesticide application machinery?

Which pesticides do you use? Natural ☐
Synthetical ☐

If you use selective pesticides, please specify

| | |
|---|---|
| Insecticide, Acaricide | |
| Fungicide | |
| Herbicide | |
| Bactericide | |

If you use natural pesticides, please specify

| | |
|---|---|
| Insecticide, Acaricide | |
| Fungicide | |
| Herbicide | |
| Bactericide | |

Name the 3 mostly used insecticides

acaricides

fungicides

herbicides

Do you follow a schedule to use pesticides? Yes ☐ No ☐

a) Application in fixed intervals (irrespectively whether the pest/disease/weed is abundant? ☐

b) Following the recommendations of the extension service (if any)? ☐

c) According to the economical threshold ☐

d) According to apple tree phenology (see below)?

| **Apple tree phenology** | **Key pests and diseases** |
|---|---|
| Green tip | |
| Tight cluster | |
| Pink | |
| Bloom | |
| Petal fall | |
| Fruit set | |

Frequency of pesticide use annually in the apple orchards

| | **Insecticide** | **Fungicide** | **Herbicide** | **Bactericide** |
|---|---|---|---|---|
| How many times a year | | | | |
| How much per application | | | | |

Purpose of pesticide use by the farmer?

Preventive ☐ Curative ☐ Both ☐

Area (hectares) treated with pesticides?

<1 hectare ☐ 1-3 hectares ☐ 3-6 hectares ☐ >6 hectares ☐

Do you keep honeybees in the orchard or nearby? Yes ☐ No ☐

If yes, is it for honey production ☐ as pollinators ☐

Do you follow the recommended pesticide dosage?
Yes, I strictly follow a/c to pesticide label and prescription ☐
I am perfect with my own experience; just see the color of the solution ☐
Use more than the recommended dosage ☐
Use less than the recommended dosage ☐

How / where you dispose the empty pesticide container after use?
Wash and reuse it for household stuffs ☐
Throw in the bushes or drainage canals ☐
Leave in the field ☐
Buried in the soil ☐
Sell for recycling and burned ☐
Separately, based on the refusal/redemption program ☐

Where do you wash sprayer and dispose the pesticide rest after pesticide application?
In the well ☐
Dispose in the orchard ☐
Dispose in the stream ☐
Do not wash ☐
Separately in a special place ☐

Do you know any natural enemies of apple pests? Yes ☐ No ☐

If yes, which natural enemies do you find in your field? (Please specify by groups)

| | |
|---|---|
| | |

**Safety of the farmer and healthy environment**

Do you have knowledge about the impacts of pesticides on health and environmental?

Yes ☐ No ☐

How do you store the pesticides?
- In a locked cabinet ☐
- In an unlocked cabinet ☐
- In the open air ☐
- Other ☐

Do you know about the waiting period? Yes ☐ No ☐

If yes, do you follow the waiting period after pesticide application?
- Strictly follow ☐
- Occasionally follow ☐
- Do not care ☐

If you do not care how long do you wait??
- Less than one week ☐
- 1-2 week ☐
- More than 2 weeks ☐
- More than one week a/c to type of pesticide ☐
- Do not wait ☐

How do you utilize the windfall of apples?
- Feed to livestock ☐
- Make it as compost or organic manure ☐
- Send it to factory to make juice ☐
- Leave it in the orchard ☐

When you use pesticide do you use?

| Specific cloth | Mask | Glass | Gloves |
|---|---|---|---|
| | | | |

Do you spray considering to wind direction? Yes ☐ No ☐

When you use pesticides do you smoke? Yes ☐ No ☐

Do you have first aid kit on your farm? Yes ☐ No ☐

What do you do in case of poisoning by pesticides in your orchard?

Have you ever faced following health impacts after pesticide application (multiple option is possible)?
- Respiratory symptoms ☐
- Skin irritation ☐
- Eye irritation ☐
- Headache ☐
- Other (specify) ☐

Have you ever been hospitalized due to the side effect of pesticide? Yes ☐ No ☐

Gender involvement in pesticide application? Male ☐ Female ☐ Both ☐

**Information flow**

Have you been trained how to maintain the orchard? Yes ☐ No ☐

If yes in which of these topics:
Recognizing pests and diseases ☐
Recognizing beneficial insects ☐
Pesticide applications ☐
Pesticide handling ☐

Which are the most important sources of crop protection advice to you (Ranking 1-3)
Extension worker(s)service(s) ☐
GardenerFarmer groups and neighbor ☐
Local NGO (non-governmental organization) ☐
Ministry of agriculture ☐
National agricultural researches center ☐
Own experience ☐
Pesticide traders ☐
Universities ☐
Other (specify)

Is there any extension service? Yes ☐ No ☐

If yes, how often do the extension service visit your farm?
Daily ☐
Weekly ☐
Monthly ☐
Every three months ☐
Half yearly or yearly ☐

How often do you visit the extension service / group meetings?
Daily ☐
Weekly ☐
Monthly ☐
Every three months ☐
Half yearly or yearly ☐

How reliable is the advice you received?
High ☐ ☐ ☐ ☐ ☐ Poor

By which media do you mostly receive the advice?
Internet ☐
Oral ☐
Phone ☐
Written info material (posters, brochures, etc) ☐

How do you decide to spray?
According to field observation ☐
Scheduled sprays ☐
According to the neighbours ☐
Other (specify)

Have you encountered cases of pesticide ineffectiveness? Yes ☐ No ☐

If yes, which?

Have you reported the cases of pesticides ineffectiveness? Yes ☐ No ☐

To whom have you reported the cases?

Which actions have been taken?

From which organization do you get information on the following? Indicate the frequency per field: 0 = never, 1 = rarely, 2 = often, 4 = very often

| **Factor** | **Extension service(s)** | **Farmer groups and neighbours** | **Local NGO (non-governmental organization)** | **Ministry of agriculture** | **National agricultural research center** | **Own experience** | **Pesticide traders** | **Universities** | **Internet** | **Others (specify)** |
|---|---|---|---|---|---|---|---|---|---|---|
| Maximum residue level | | | | | | | | | | |
| Registered pest control products | | | | | | | | | | |
| Safety pest control products | | | | | | | | | | |
| Pesticide application techniques | | | | | | | | | | |
| Rules and regulations on pest control products | | | | | | | | | | |
| Prediction of Whether condition | | | | | | | | | | |
| Other | | | | | | | | | | |

Which media provide the information? Indicate the frequency per field: 0 = never, 1 = rarely, 2 = often, 4 = very often

| **Factor** | **Internet** | **Oral formal meet-ing (s)** | **Oral informal meetings** | **Phone** | **Poster(s)** |
|---|---|---|---|---|---|
| Maximum residue level | | | | | |
| Registered pest control products | | | | | |
| Safety of pest control products | | | | | |
| Pesticide application tech-niques | | | | | |
| Rules and regulations on pest control products | | | | | |
| Weather forecast | | | | | |
| Other | | | | | |

Please specify IPM measures you use in apple orchard?

| Practice | Specific type | When applied | Purposed used | Frequency of use |
|---|---|---|---|---|
| | | | | |
| Biological control agents | | | | |
| Flowering plants | | | | |
| Disease infection periods forecast | | | | |
| Insect pest forecast | | | | |
| Mechanical weeders | | | | |
| Monitoring | | | | |
| Organic control options | | | | |
| Repellents | | | | |
| Removal of infested materials | | | | |

Do you know the activity and phenology of common pests and diseases? Yes ☐ No ☐

Have you encountered any problems in the use of above-mentioned IPM practices in apple?

Yes ☐ No ☐

If yes, please name them and ways you have solved the problems?

| Pest management practice | Problem encountered | Solution of the problem |
|---|---|---|
| | | |

Have you participated in an IPM training program? Yes ☐ No ☐

If yes; who offered the training program?

Extension service(s) ☐
Farmer groups and neighbors ☐
Local NGO ☐
Ministry of agriculture ☐
National agricultural research center ☐
Pesticide traders ☐
Universities ☐
Retailer companies ☐

Who initiated contacts between you and IPM training course?

Extension service(s) ☐
Farmer groups and neighbours ☐
Local NGO ☐
Ministry of agriculture ☐
National agricultural research center ☐
Pesticide traders ☐
Universities ☐
Retailer companies ☐

Do you feel the information you receive was complete? Yes ☐ No ☐

If no, please specify which topics were lacking or not satisfactory enough?

Do you communicate or share the information you received? Yes ☐ No ☐

If yes, please specify with whom and how?

| **WHO?** | **Direct contact** | **Handy** | **Group meeting** | **Hearing** |
|---|---|---|---|---|
| Extension service(s) | | | | |
| Gardner group and neighbors | | | | |
| Local NGO | | | | |
| Ministry of agriculture | | | | |
| National agricultural research center | | | | |
| Pesticide traders | | | | |
| Universities | | | | |
| Retailer companies | | | | |

In your opinion, what should be done to improve the acquisition and delivery of apple pest management information?

Table A 3.1. The families, genera and life-style (k, koinobiont) of larval parasitoids of Tortricidae and Gelechiidae found in Baden-Württemberg.

| **Parasitoid guild** | **Parasitoid life-style** | **Order** | **Family** | **Subfamily** | **Species represented** |
|---|---|---|---|---|---|
| Egg-larval | K | HYM | BR | Cheloninae | *A. quadridentata* Wesmael |
| Larval | K | HYM | BR | Macrocentrinea | *M. linearis* Nees |
| | K | HYM | ICH | Cremastinae | *P. vulnerator* Panzer |
| Early-Stage larval | K | HYM | BR | Microgastrinae | *A. xanthostigma* Haliday |
| Late-stage larval | K | HYM | BR | Agathinae | *A. pini* Muesbeck |
| | K | HYM | BR | Braconinae | *B. gelechiae* Ashmead |
| Larval-pupal | K | HYM | ICH | Anomalinae | *T. enecator* Rossi |
| Larval-cocoon | K | HYM | ICH | Metopiinae | *C. funebris* Gravenhorst |
| | K | HYM | ICH | Pimplinae | *L. caudatus* Ratzeburg |
| | K | HYM | ICH | Pimplinae | *S. hispae* Harris |
| | K | HYM | ICH | Tryphoninae | *P. polyzonias* Foerster |

Abbreviated names: family (BR: Braconidae, ICH: Ichneumonidae); order (Hym.: Hymenoptera); parasitoid life cycle (K: Koinobiont).

Table A 3.2. Host and parasitoid species relationships and the abundances of different larval parasitoids found in this study through different years in apple orchards in Baden-Württemberg.

| **Family, subfamily and species** | **Host species** | **DEN** | **EMM** | **GOG** | **HOH** | **ILS** | **LCO** | **NEU** | **PLI** | **RIE** | **ROM** | **SCH** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Braconidae | | | | | | | | | | | | |
| Agathidinae | | | | | | | | | | | | |
| *A. pini* | CYDPOM | | | | | | 1 | | | | | |
| Braconinae | | | | | | | | | | | | |
| *B. gelechiae* | ARCXYL | | | | | | | | 1 | | | |
| | HEDNUB | | | 4 | | | | 2 | 9 | | | |
| | RECLEU | | | | | | | | 8 | | | |
| Cheloninae | | | | | | | | | | | | |
| *A. quadriden-tata* | CYDPOM | | 2 | | | | | | 5 | | | |
| | SPIOCE | | | | | | | | 3 | | | |
| Macrocentrinae | | | | | | | | | | | | |
| *M. linearis* | HEDNUB | | | 1 | | | | | | | | |
| | RECLEU | | | | | | | | | | | 1 |
| | SPIOCE | | | | | | | 2 | | | | 3 |

Table A 3.2. (continued)

| **Family, subfamily and specis** | **Host species** | **DEN** | **EMM** | **GOG** | **HOH** | **ILS** | **LCO** | **NEU** | **PLI** | **RIE** | **ROM** | **SCH** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Microgastrinae** | | | | | | | | | | | | |
| *A. xan- thostigma* | ARCXYL | | | | | | | | 1 | 1 | | |
| | HEDNUB | | | 2 | | | | 1 | 7 | | | 1 |
| | RECLEU | | | 5 | | | | 3 | 1 | | | 1 |
| | SPIOCE | | | | | | | | | | | 1 |
| Ichneumonidae | | | | | | | | | | | | |
| Anomalinae | | | | | | | | | | | | |
| *T. enecator* | CYDPOM | 3 | 68 | | 15 | 4 | 4 | | 38 | | 4 | |
| Cremastinae | | | | | | | | | | | | |
| *P. vulnerator* | CYDPOM | | 11 | | | 1 | 1 | | 26 | | 2 | |
| | RECLEU | | | 1 | | | | | | | | |
| | HEDNUB | | | | | | | | 1 | | | |

Table A 3.2. (continued)

| Family, subfamily and species | Host species | DEN | EMM | GOG | HOH | ILS | LCO | NEU | PLI | RIE | ROM | SCH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Metopiinae | | | | | | | | | | | | |
| *C. funebris* | RECLEU | | | | | | | 2 | 2 | | | |
| | SPIOCE | | | | | | | | | | | 1 |
| Pimplinae | | | | | | | | | | | | |
| *L. caudatus* | CYDPOM | | 7 | | 1 | | 1 | | 1 | | | |
| | RECLEU | | | | | | | | 4 | | | |
| | SPIOCE | | | | | | | | 2 | | | |
| *S. hispae* | CYDPOM | 4 | 21 | | | | | | | | | |
| Tryphoninae | | | | | | | | | | | | |
| *P. polyzonias* | CYDPOM | | | | 1 | | | | 3 | | 1 | |
| | RECLEU | | | 1 | | | | | 1 | | | |
| | SPIOCE | | | | | | | 1 | | | | |
| Un. 1 | CYDPOM | | | | | 1 | | | 3 | | | |

Table A 3.2. (continued)

| Family, subfamily and species | Host species | DEN | EMM | GOG | HOH | ILS | LCO | NEU | PLI | ROM | SCH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Un. 2 | HEDNUB | | | | | | | | 3 | | |
| | RECLEU | | | | | | | | 2 | | |
| | SPIOCE | | | | | | | | 2 | | |
| Perilampidae | | | | | | | | | | | |
| *P. tristis* | CYDPOM | | | | | | | | 4 | 1 | |
| **Total** | | **7** | **109** | **14** | **17** | **6** | **7** | **11** | **136** | **8** | **8** |

Abbreviated phytophagous species: Tortricidae: ARCXYL (*Archips xylostena*); CYDPOM (*Cydia pomonella*); HEDNUB (*Hedya nubiferana*); SPIOCE (*Spilonota ocellana*). Gelechiidae: RECLEU (*Recurvaria leucatella*).

Abbreviated location names: DEN (Denzlingen); EMM (Emmendingen); GOG (Goldener Grund); HOH (Hohenheim); ILS (Ilsfeld); LOC (Lake of Constance); NEU (Neuhausen); PLI (Plieningen); ROM (Romelshausen); SCH (Scharnhausen).

Table A 3.4. Fauna similarity indices for different apple orchards 2012.

| Jaccard | | Renkonen | | Wainstein | |
|---|---|---|---|---|---|
| | PLI | | PLI | | PLI |
| HOH | 40 | HOH | 31.14 | HOH | 1245.71 |

Table A 3.5. Fauna similarity indices for different apple orchards 2013.

| Jaccard | | Renkonen | | Wainstein | |
|---|---|---|---|---|---|
| | HOH | | HOH | | HOH |
| PLI | 25.0 | PLI | 39.22 | PLI | 980.39 |

Table A 3.6. Fauna similarity indices for different apple orchards 2014.

| Jaccard | | | | | |
|---|---|---|---|---|---|
| | GOG | ILS | LOC | PLI | ROM |
| GOG | | | | | |
| ILS | 16.67 | | | | |
| LOC | 0 | 33.33 | | | |
| PLI | 36.36 | 20 | 20 | | |
| ROM | 28.57 | 50 | 20 | 27.27 | |
| **Renkonen** | | | | | |
| | GOG | ILS | LOC | PLI | ROM |
| GOG | | | | | |
| ILS | 7.14 | | | | |
| LOC | 0 | 66.67 | | | |
| PLI | 41.29 | 51.22 | 34.14 | | |
| ROM | 14.29 | 66.66 | 50 | 51.22 | |
| **Wainstein** | | | | | |
| | GOG | ILS | LOC | PLI | ROM |
| GOG | | | | | |
| ILS | 119.05 | | | | |
| LOC | 0 | 2222.22 | | | |
| PLI | 1501.43 | 1024.39 | 682.92 | | |
| ROM | 408.16 | 3333.33 | 1000 | 1396.90 | |

Table A 3.7. Fauna similarity indices for different apple orchards 2015

| **Jaccard** | | | | | |
|---|---|---|---|---|---|
| | DEN | EMM | NEU | PLI | SCH |
| DEN | | | | | |
| EMM | 40 | | | | |
| NEU | 0 | 0 | | | |
| PLI | 0 | 10 | 57.14 | | |
| SCH | 0 | 0 | 60 | 28.57 | |
| **Renkonen** | | | | | |
| | DEN | EMM | NEU | PLI | SCH |
| DEN | | | | | |
| EMM | 62.12 | | | | |
| NEU | 0 | 0 | | | |
| PLI | 0 | 1.83 | 57.42 | | |
| SCH | 0 | 0 | 67.04 | 42.11 | |
| **Wainstein** | | | | | |
| | DEN | EMM | NEU | PLI | SCH |
| DEN | | | | | |
| EMM | 2484.93 | | | | |
| NEU | 0 | 0 | | | |
| PLI | 0 | 18.35 | 3280.93 | | |
| SCH | 0 | 0 | 4022.72 | 1203.01 | |

Table A 3.8. Distribution frequency of classes of education level of the owners by provinces and region.

| Province / region | Illiterate | Primary level | Secondary level | Diploma | University (agri.) | University (irrelevant) |
|---|---|---|---|---|---|---|
| **E. Azerbaidjan** | **0** | **0** | **3** | **1** | **0** | **1** |
| Marand | 0 | 0 | 3 | 1 | 0 | 1 |
| **Fars** | **2** | **3** | **1** | **2** | **1** | **0** |
| Abadeh | 0 | 0 | 0 | 0 | 0 | 0 |
| Ardekan | 1 | 0 | 0 | 1 | 1 | 0 |
| Hamayjan | 1 | 2 | 1 | 0 | 0 | 0 |
| Sepidan | 0 | 1 | 0 | 1 | 0 | 0 |
| **Isfahan** | **0** | **0** | **1** | **3** | **3** | **1** |
| Padenaolia | 0 | 0 | 1 | 2 | 3 | 1 |
| Semirom | 0 | 0 | 0 | 1 | 0 | 0 |
| **Tehran** | **0** | **4** | **1** | **4** | **0** | **0** |
| Damavand | 0 | 4 | 1 | 4 | 0 | 0 |
| **W. Azerbayjan (total)** | **0** | **3** | **0** | **2** | **0** | **0** |
| Nazlu-chai | 0 | 3 | 0 | 0 | 0 | 0 |
| Baranduz-chai | 0 | 0 | 0 | 1 | 0 | 0 |
| Bakeshlu-chai | 0 | 0 | 0 | 1 | 0 | 0 |
| Total | 2 | 10 | 6 | 12 | 4 | 2 |

Table A 3.9. Frequency of farmers visits to crop protection experts by age of the owner, distance to experts, and education level of the owner.

| Source | Nr. of parameters | d.f. | Chi square | P |
|---|---|---|---|---|
| Age of the owner | 5 | 5 | 7.4650 | 0.1883 |
| Distance to experts (classes) | 3 | 3 | 0.4540 | 0.9289 |
| Education level of the owner | 5 | 5 | 6.4393 | 0.2658 |

(Ordinal-logistic fit, Full model test: d.f. = 13, $Chi^2$ = 14.0225, P = 0.3723; $r^2$ = 0.1444, AICc = 153.067, observations = 35)

Table A 3.10. The frequency and distribution of apple cultivars in different provinces in Iran.

| | Braeburn | Delbar estivale | French | Fuji | Gala | Golden delicious | Granny Smith | Golab (local cultivar) | Malling | Miracle | Red delicious | Star King |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| E. Azerbaidjan | 0 | 0 | 0 | 0 | 1 | 6 | 2 | 5 | 0 | 0 | 6 | 0 |
| Fars | 0 | 0 | 1 | 0 | 0 | 10 | 1 | 6 | 1 | 0 | 10 | 0 |
| Isfahan | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 7 | 0 | 0 | 8 | 0 |
| Tehran | 1 | 2 | 1 | 4 | 7 | 9 | 2 | 4 | 5 | 2 | 9 | 2 |
| W. Azerbayjan | 0 | 0 | 0 | 0 | 0 | 5 | 2 | 2 | 0 | 0 | 5 | 0 |

Table A 3.11. Total number of insecticide/acaricide applications by maximum number of extension service, reliability to their advice and provinces.

| Source | d.f. | Chi square | P |
|---|---|---|---|
| Maximum extension service contacts | 5 | 16.4986 | 0.0056 |
| Reliability of advice | 5 | 9.3600 | 0.0955 |
| Province | 4 | 3.1824 | 0.5278 |

Ordinal-logistic fit, Full model test: d.f. = 14, $Chi^2$ = 25.1402, P = 0.0332; $r^2$ = 0.1972, AICc = 198.686, observations = 39)

Table A 3.12. The distribution frequency of apple area cultivation (ha) in different provinces in Iran.

| Province / region | **1 (ha)** | **2 (ha)** | **3 (ha)** | **4 (ha)** |
|---|---|---|---|---|
| **E. Azerbaidjan** | **0** | **2** | **3** | **1** |
| Marand | 0 | 2 | 3 | 1 |
| **Fars** | **6** | **3** | **1** | **0** |
| Abadeh | 1 | 0 | 0 | 0 |
| Ardekan | 2 | 0 | 1 | 0 |
| Hamayjan | 1 | 3 | 0 | 0 |
| Sepidan | 2 | 0 | 0 | 0 |
| **Isfahan** | **2** | **4** | **2** | **0** |
| Padenaolia | 2 | 4 | 1 | 0 |
| Semirom | 0 | 0 | 1 | 0 |
| **Tehran** | **1** | **4** | **1** | **4** |
| Damavand | 1 | 4 | 1 | 4 |
| **W. Azerbayjan** | **2** | **3** | **0** | **0** |
| Nazlu-chai | 1 | 2 | 3 | 0 |
| Baranduz-chai | 1 | 0 | 1 | 0 |
| Bakeshlu-chai | 0 | 1 | 0 | 0 |
| Total | 11 | 16 | 7 | 5 |

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# CURRICULUM VITAE

## PERSONAL DATA

| | |
|---|---|
| Family, name: | Lashkari-Bod, Abdullah |
| Gender: | Male |
| Date of birth: | 21.05.1980 |
| Marital status: | married |

## EDUCATION

| | |
|---|---|
| 10.1999 - 07.2003 | **B.Sc. Iran**, Azad University, Faculty of Agriculture Engineering, Department of Plant Protection |
| 10.2006 - 05.2009 | **M.SC. Iran**, Zabol University, Faculty of Agriculture, Department of Plant Protection |
| 09.2011 - 02.2019 | **Ph.D. Germany**, Hohenheim University, Faculty of Agriculture, Institute of Phytomedicine, Department of Applied Entomology |

## PUBLICATION

Fischer, M., **A. Lashkari-Bod**, E. Rakhshani, and A. A. Talebi, 2011. Alysiinae From Iran (Insecta: Hymenoptera: Braconidae: Alysiinae). Ann. Naturhist. Mus. Wien-B, 112: 115-132.

**Lashkari-Bod, A.**, E. Rakhshani, A. A. Talebi, A. Lozan, and V. Žikić. 2011. New records of Cheloninae (Förster, 1862) and Braconinae (Nees, 1811) (Insecta: Hymenoptera: Braconidae) from Iran. Check list, Journal of species lists and distribution. 7:632- 634.

**Lashkari-Bod, A.**, E. Rakhshani, A. A. Talebi, A. Luzan, and V. Žikić. 2011. A Contribution to the knowledge of Braconidae (Hym., Ichenumonoidea) of Iran. Biharean Biologist. 5: 147-150.

**Lashkari-Bod, A.,** and C. P. W. Zebitz. 2014. Diversity and abundance of parasitoids in organic apple orchards in Baden-Württemberg. In: FÖKO (ed.) eco-fruit – 16th Intl. Conf. on Organic Fruit-Growing, 17. – 19. Feb. 2014, Stuttgart-Hohenheim/Germany. 195-198.

## WORK EXPERIENCE

| | |
|---|---|
| 05.2004 - 09.2005 | **Expert** of plant protection in administration of agriculture |
| 10.2010 - 02.2011 | **Lecturer** of entomology at Azad University of Shiraz. Technical English language, Entomology; Zoology; Introductory entomology; Systematic entomology; Toxicology; Principles of pests control; Fruit, agronomic plants and storage room pests. |

## WORKSHOPS

| | |
|---|---|
| 12.2011 | “Learning intercultural competence” |
| 03.2012 | “Working within political contexts strategies and methods for implementation-oriented research” |
| 10.2013 | “Basics of taxonomy: describing, illustrating and communication biodiversity” (DEST) |

| | |
|---|---|
| 06.2014 | “Leadership development” |
| 01.2017 | “Insect pest control strategies and methodologies: theory and practice” (BINGO) |
| 03.2017 | “Integrative taxonomy and taxonomic expertise: DNA barcodes in the genomic era” (DEST) |

**CONFERENCES AND FORUMS**

| | |
|---|---|
| 10.2011 | “World food day colloquium” |
| 01 - 2012, 2013, 2014 | “Global forum for food and agriculture” |
| 09.2012 | “First international conference on global food security” |
| 09 - 2012, 2014 | “Tropentag” |
| 06.2013 | “Change agents” |
| 02.2014 | “Eco-fruit” |

**MEMBERSHIP**

| | |
|---|---|
| 07.2012 - 07.2015 | Entomological Society of America (ESA) |
| 03.2016 - 03.2017 | International Organization for Biological and Integrated Control (IOBC) |

**LANGUAGE SKILLS**

| | |
|---|---|
| DEUTSCH | B 2.1. |
| ENGLISH | TOEFL, iBT (90/120) |
| FRENCH | Medium |
| PERSIAN | Mother language |

**ADDITIONAL SKILLS AND INTERESTS**

| | |
|---|---|
| SOFTWARE CAPABILITIES | VECTOR GRAPHIC SOFTWARE<br>(Adobe Illustrator; Inkscape)<br>IMAGE EDITING SOFTWARE<br>(Adobe Photoshop)<br>MICROSOFT OFFICE<br>(Excel; Power point; Word)<br>STATISTICAL COMPUTING SOFTWARE<br>(JUMP (basic); PAST; R (basic)) |
| SCIENTIFIC INTERESTS | Taxonomy, systematics, phylogeny, biology (life history, symbiotic viruses) and biodiversity of parasitoid wasps |